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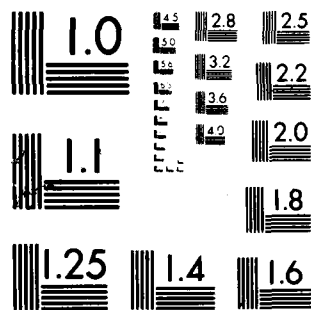
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AUTOMATIC PROCESSING AND THE UNITIZATION OF TWO FEATURES

Walter Schneider and Ray Eberts

REPORT No. 8008

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Automatic Processing and the Unitization
of Two Features

Walter Schneider and Ray Eberts

Report 8008

Human Attention Research Laboratory
University of Illinois, Urbana-Champaign
February, 1980

Abstract

In a series of experiments conjunction target detection search (color and shape) was compared with single feature search (color or shape). Within appropriate training and sufficient practice, subjects could unitize the features in the conjunction condition. Unitization was defined as occurring when performance of the conjunction condition was similar to performance on a single feature condition. In four visual search experiments, performance on conjunctions and single feature shape searches was highly similar across three criteria: 1) slope; 2) positive to negative slope ratios; and 3) percent variance accounted for by the linear component. In another experiment, unitization was shown to be dependent on the type of mapping, either consistent or varied, in a multiple-frame detection experiment. Two other experiments further examined characteristics of single and conjunction feature conditions. In one, the stability of the integral-separable dimension distinction was examined across time. Problems with this approach and distinctions between integrality and unitization were discussed. Another experiment compared single feature and conjunction conditions in a texture segregation task. With training, conjunction performance was about equal to or better than initial single feature conditions. The relationships between unitization and automatic processing were discussed.

Color Experiments

The processing of multidimensional stimuli has been examined under several different methodologies and theoretical orientations. Stimulus processing has been examined with respect to serial or parallel processing of features. Features have been described to be either separable or integral. A recent study by Treisman and Gelade (1980) and the series by Schneider and Shiffrin (1977; Shiffrin and Schneider, 1977) suggests that a new question can be proposed: Can a two feature stimulus with values along two separable dimensions become unitized so that the conjunction stimulus takes on the characteristics of a stimulus that varies along only one dimension? To put this question in the proper perspective, a brief review of research on the parallel versus serial and integral versus separable issues follows.

The results from the serial versus parallel experiments on multidimensional stimuli are equivocal. The task is typically to indicate whether or not a stimulus satisfies category criteria (see, for example, Nickerson, 1967). The number of relevant attributes (e.g., large and red and circle) is varied. In a review, Grill (1971) found that about an equal number of studies hypothesized both parallel and serial searches from their results. Still another group of experiments found totally equivocal results and could not predict one or the other. Although the possible results for several kinds of serial searches and several kinds of parallel searches were modeled (Egeth, 1966; Hawkins, 1969), the results from the experiments did not seem to adhere completely to any particular serial or parallel model. Conclusions were usually based upon some more global characteristics. The issue was further complicated when Townsend (1972) showed that different serial and parallel models could postulate the same results. The question of whether multidimensional stimuli are processed serially or in parallel is still unanswered.

Shepard (1964), using multidimensional scaling techniques, distinguished between analyzable and unanalyzable stimuli. Garner (1970, 1974a) brought the concept into cognitive psychology making a similar distinction between separable and integral dimensions. Several experiments followed that were designed to classify dimensions into separable and integral groups. Recently, the distinction between the two classifications has become blurred as dimensions have been discovered that take on both separable and integral characteristics (Garner and Felfoldy, 1970)

In an interesting experiment, LaBerge (1973) showed that with practice two features could be automatically unitized to form a novel character. We wish to address a similar question. First, unitization must be defined. Unitization is not separable dimensions becoming integral; dimensional structures deal with dimensions while unitization is concerned with combination of features on the dimensions. It is not characterized by parallel as opposed to serial search; the type of search often depends on the task, discriminability of targets from distractors, and other situation specific considerations which make it difficult to distinguish one from the other. Instead, unitization can occur when a two feature¹ stimulus behaves like a one feature stimulus. As an empirical definition, unitization occurs when a search for a target which requires the separate identification of two features is not qualitatively different from a search for a target which requires identification of one of the features alone.

Indeed, LaBerge (1973) used a similar implicit definition of unitization when he showed that novel characters exhibited similar characteristics to familiar letters after practice. The unitization process should require extensive practice and the proper type of training.

Treisman's (Treisman and Gelade, 1980) feature-integration theory of attention postulates that features are identified before objects and that focal attention is the "glue" that combines the separate features into the objects. Because focal attention is required, each item in a display must be attended to separately. Thus, search must be serial in a display that requires the identification of two features (a conjunction condition). If only one feature is required for discrimination, the search can be in parallel. The visual search experiments of Treisman and Gelade (1980) confirmed this hypothesis.

Schneider and Shiffrin (1977; Shiffrin and Schneider, 1977) take a somewhat different approach to a theory of attention. They hypothesize that there are two qualitatively different kinds of processes - automatic and controlled. An automatic process is: 1) not demanding of attentional capacity; 2) characterized by parallel search; 3) established with much difficulty; 4) not easily altered; 5) difficult to reverse; 6) difficult to suppress; and 7) unaffected by load. A controlled process is: 1) highly demanding of attentional capacity; 2) characterized by serial search; 3) easily established; 4) easily altered; 5) easily reversed; 6) easily suppressed; and 7) affected by load requirements. The type of training is important. If targets and distractors are consistently mapped (a CM condition) - a target is always a target and never a distractor - an automatic process will develop with practice. On the other hand, if targets and distractors are variably mapped (a VM condition) - a target is a target on one trial and a distractor on the next - controlled processing will be maintained.

Treisman and Gelade (1980), in their visual search experiments, varied the number of distractors in a display. Subjects were to search for either a conjunction target or a disjunction target. In the conjunction condition, subjects had to identify and localize two features to separate target from distractors (e.g., Target=green T; Distractors=brown T, green X). In the disjunction condition, either one of the two features would distinguish target from distractors (e.g., Target=blue T or blue X; Distractors=brown T, green X). Treisman and Gelade hypothesized that the searches for the two conditions, conjunction and disjunction, should be qualitatively different from each other. The conjunction search requires focal attention and should be serial in nature; the disjunction search can be fast and parallel. Schneider and Shiffrin, on the other hand, would predict that with the right kind of training, qualitative differences between a conjunction search and disjunction search would disappear with practice. Instead, qualitative differences would only exist between CM and VM trained sequences. The features in the conjunction condition could possibly become unitized so that focal attention would not be needed.

Experiment 1 - Visual Search I

Treisman and Gelade (1980) found qualitative differences between the conjunction and disjunction conditions across three measurements: 1) slope; 2) the ratio of positive to negative slope; and 3) the variance accounted for by

the linear component. In the conjunction condition the positive slope was 28.7 msec/item, the ratio was 0.43, and the variance accounted for was over 99% for both positive and negative trials. In the feature disjunctive condition the positive slope was 3.2 msec/item, the ratio was 0.13, and the variance accounted for was only 68% for positive trials.

In this experiment, a visual search procedure similar to Treisman and Gelade (1980) was used with a few important differences. First, a CM training procedure similar to Schneider and Shiffrin (1977) was used. Second, subjects received a large amount of practice. Finally, the conjunction condition was compared to a single dimension condition across the two possible dimensions. In an earlier experiment, Treisman, Sykes, and Gelade (1977) compared a conjunction search to single dimension searches. In that experiment, the shape and color uni-dimensional searches appeared to be qualitatively different from each other. The use of a disjunctive search by Treisman and Gelade (1980), rather than a uni-dimensional search, provided only a combined negative reaction time. Since the relationship between the positive and negative slopes is a major qualitative measure of conjunction and single feature searches, the disjunction test is a weaker single control condition. Hence, the disjunction search could have possibly hidden differences that might exist between the color and shape uni-dimensional searches. In turn, a conjunction search could be similar to a shape or color uni-dimensional search and not similar to a shape or color disjunction search.

Experiment 1 examines several hypotheses. First, after sufficient practice and CM training, there should be no qualitative differences between the conjunction condition and either one of the single dimension conditions. This would provide initial evidence for the unitization of the two features across the two conditions. Second, it is expected that the qualitative differences between conjunction and disjunction - slope, linear component, and ratio - will not be evident when subjects are practiced and the conjunction condition is compared to the appropriate single dimension condition. The conjunction condition is expected to be somewhat inferior to the worst of the single dimension conditions, but to show no qualitative differences from it.

Method

Stimuli. Subjects were divided into two groups. One group searched for a green X target in a display of distractors and the other searched for a red T. The targets always remained the same throughout the experiment for each subject. The distractors changed according to the stimulus condition. For the green X (red T) target group, the distractors for each condition were the following (red T distractors are in parentheses): 1) Shape--distractors were green T's (red X's); 2) Color--distractors were red X's (green T's); and 3) Conjunction--distractors were both green T's and red X's (green T's and red X's).

The display size was either 3, 6, or 15 items. One of the items could be a target depending on whether the trial was positive (target present) or negative (no target). Each letter subtended about .25 x .45 degrees of arc and appeared on a dark background. The character dot matrix on the color terminal was 5 dots wide by 7 dots high. Only part of the screen was used for the total display

which subtended about 6.5×6.5 degrees of arc. The display consisted of a 20×14 matrix so that letters could appear in 279 possible positions (the fixation dot in the middle position remained on throughout the trial). The distractors and target (if there was one) were randomly placed so that each had an equal probability of occurrence in all positions. In the conjunction condition where the number of distractors was odd, the extra distractor was randomly selected from the two possible choices.

Subjects. The six subjects were undergraduate volunteers at the University. All had normal or corrected-to-normal vision and were paid for their participation.

Apparatus. The experiment was computer-controlled by a PDP 11/34. The stimuli appeared on an Intelligent Systems Corp. model 8001G color terminal modified so all letters would appear on the screen simultaneously when the scan line was at the top of the screen. Two subjects generally were seated in front of the screen so that both saw the same display. Subjects were separated by a cloth partition so that they could not see each other. Each subject wore a headset through which white noise and error feedback tones were carried.

Procedure. The response was a two-choice reaction time task. The index and ring fingers of the dominant hand were placed over two buttons on a response box. Two-thirds of the subjects in each target condition pushed the left button if a target appeared in the display (positive trial) and the right button if no target appeared (negative trial). The remaining subjects had the opposite assignment.

Each trial consisted of the following sequence of events. The words "Target" and "Distractor(s)" in white letters, with the corresponding colored letters for each condition underneath, appeared at the very top of the screen for a maximum of 30 seconds or until both subjects initiated the trial by pushing a button with the non-dominant hand on a separate response box. A fixation dot appeared in the middle of the screen. Then, 500 ± 8.3 msec later, the display came on; the focus dot remaining on the screen. The display terminated as soon as both subjects responded or after 4 seconds. Immediate feedback was given to a subject making an error by turning on a red light on the response box and sounding a tone on the subject's headset.

A block consisted of 106 trials of which the first 10 were practice and were not analyzed. The conjunction, slope, and color condition blocks together will be termed a replication. Blocks were randomized within groups of six blocks. Each subject received 108 blocks for a total of 10,368 (10,728) trials (the numbers in parentheses include practice trials). This experiment lasted about 9 hours.

Results

One of the subjects was consistently late to the experiment and was later terminated. The results from the remaining five subjects are depicted in Figure 1. Each point in the figure represents averaged scores for 6 replications (576 trials per subject per condition). Both the shape and conjunction conditions are characterized by decreasing slopes across time. Errors were fairly constant

so that improvements with practice cannot be explained by a speed-accuracy tradeoff.

Insert Figure 1 about here

Slopes were very low for the color condition across time. Positive slope was 3.06 msec/item for the first six replications and 1.81 msec/item for the last six replications. Negative slope was 2.40 msec/item for the first six replications and -0.32 msec/item for the last six replications. There was much more improvement for the shape and conjunction conditions with time. Positive slope for the conjunction condition improved from 25.92 msec/item to 11.37 msec/item while negative slopes improved from 52.21 msec/item to 27.32 msec/item. In the shape condition, the positive slope improvement was from 16.18 to 9.56 while the negative slope improvement was from 33.97 to 18.50. There is only a 1.81 msec/item difference between positive slopes in the conjunction and shape conditions.

The ratio of positive to negative slopes was similar for the shape and conjunction conditions. The shape ratio was 0.48 for the first 6 replications and 0.52 for the last 6 replications in the shape condition. The ratio was 0.50 to start and 0.42 at the end of the conjunction condition. The slope ratios were unstable and different in the color condition. It was 1.28 in the first 6 replications and -5.66 in the last 6 replications.

The variance accounted for by the linear component was over 99% in the shape and conjunction condition (see Figure 2 for RT plotted against display size for the last 6 replications). The color condition was slightly different. For the last 6 replications of the negative color condition, the variance accounted for was 48.1%. For the positive search in the last six replications and the two search conditions in the first six replications, the variance accounted for by the linear component was always over 98%.

Insert Figure 2 about here

Discussion

Although the color condition always behaved differently, there did not seem to be qualitative differences between the shape and conjunction conditions. The variance accounted for by the linear components of the shape and conjunction was similar, the slope ratios were similar, and the slopes themselves were different by only 1.81 msec/item. So, apparently the condition where two features are needed to discriminate the target from distractor (the conjunction), is not qualitatively different from a condition where only one feature is needed for the discrimination (the shape condition). The color condition is entirely different from either - very low slope with the negative slope actually smaller than the positive slope.

The qualitative differences noticed by Treisman and Gelade (1980) between the conjunction and single feature search conditions were not found in this experiment. Whereas they found 68% of the variance accounted for by the

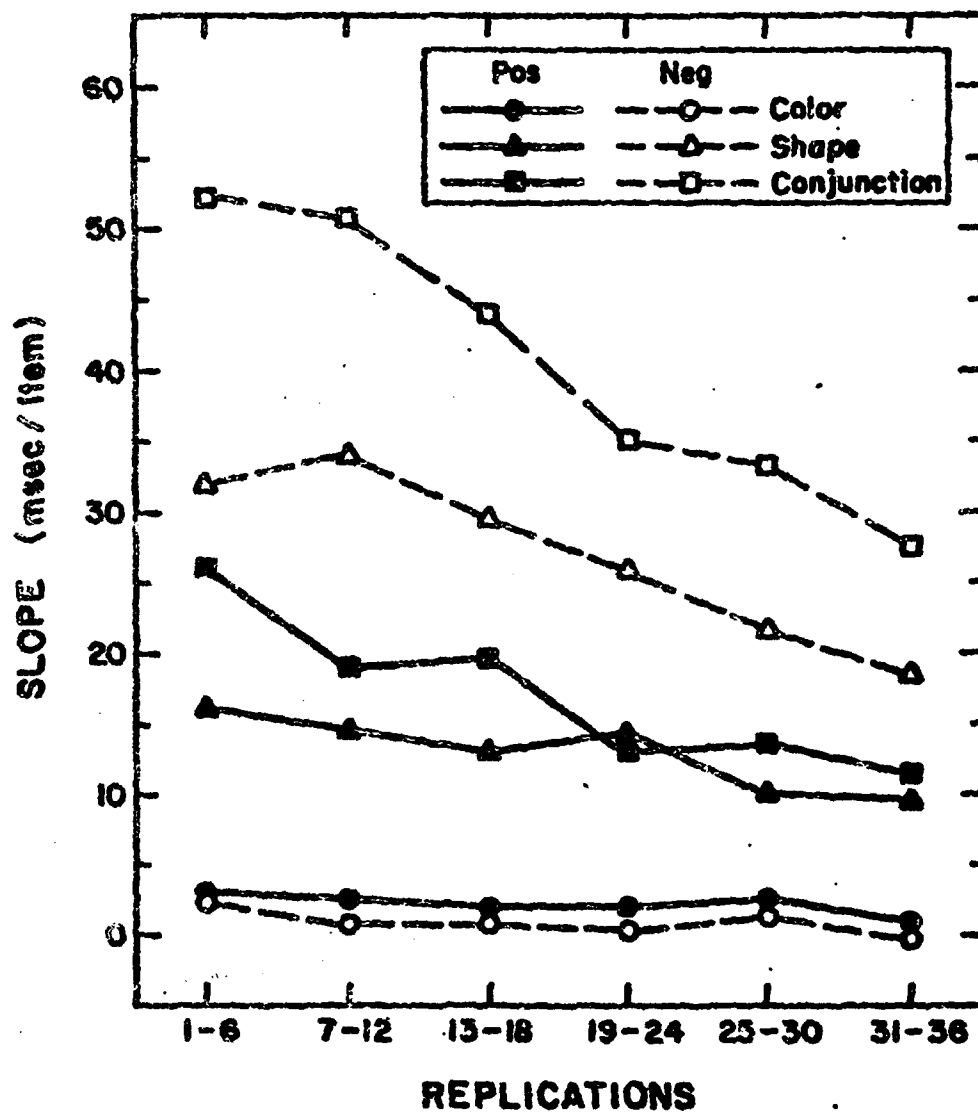


Figure 1. Data from Experiment 1: slopes across all replications for positive and negative trials of the color, shape, and conjunction conditions.

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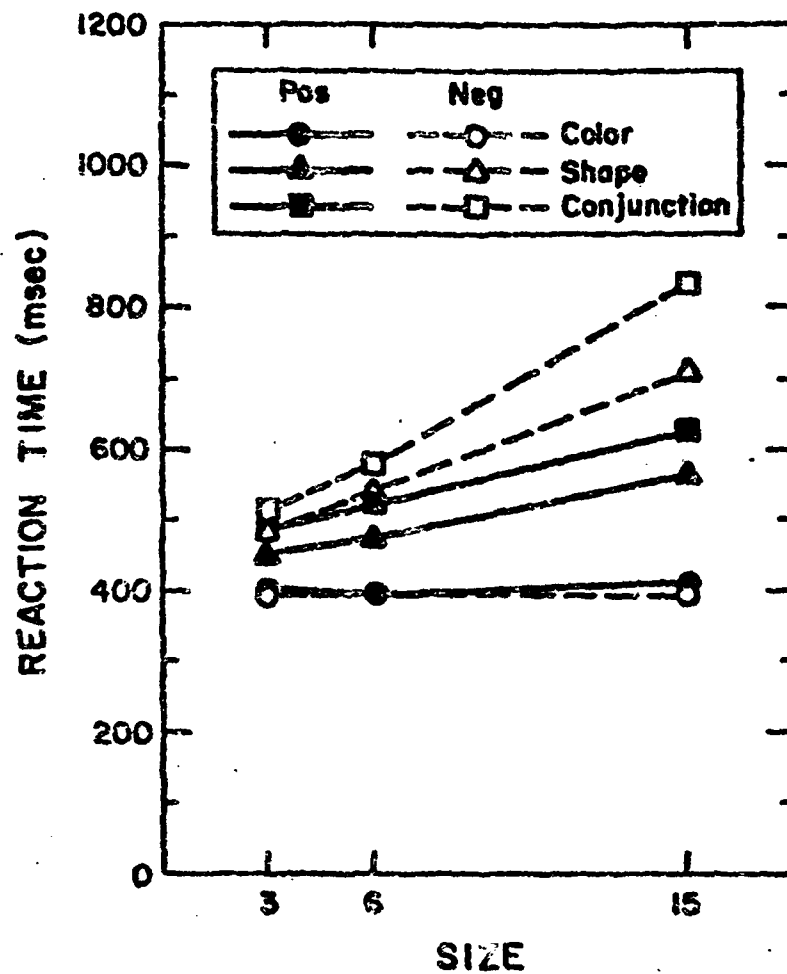


Figure 2. Data from Experiment 1: Mean reaction times as a function of display size for positive and negative trials of the color, shape, and conjunction conditions.

positive slope in the disjunction condition, we found over 90% variance accounted for in the single feature shape condition. Perhaps their result occurred because of the method of randomization used. They divided the display in sections and placed items by eye in the different sections. In the many item conditions, it becomes much harder to place items randomly. Indeed, it appears that the nonlinearity noticed in the positive disjunction condition appears to be due to a leveling off after the 15 item display condition. In their Experiment II, they attempted to correct for the randomization problem but failed to run the condition where the different linear component was found earlier. Also, we failed to find the different slope ratios for the two features and one feature searches.

Although there are very many parallel and serial models (Egeth, 1966) perhaps the classic parallel model could be characterized as having low slope and a positive to negative slope ratio of about one. The results from the conjunction condition did not fit that model. The color condition was the only one that exhibited the classic parallel results. Disregarding the issue of the slope ratios, it is difficult to say what constitutes a low enough slope to call the results parallel. Although it is difficult to compare slopes across experiments where stimuli and display saliences change, we found a positive slope of 11.37 msec/item after practice in the conjunction condition which is quite small when compared to the 28.7 msec/item positive conjunction slope found by Treisman and Gelade (1980) and the 37 msec/item slope found for Sternberg's (1967) serial exhaustive search experiment. The important results remain, however, that the shape and conjunction conditions were very similar. It cannot be expected that the conjunction conditions would exhibit the classic parallel search tendencies when the shape condition exhibits serial tendencies.

Treisman, Sykes, and Gelade (1977) used the single dimensions of shape and color as control conditions for the conjunction. They found slope ratios for the shape and conjunction conditions that were similar to ours although their quantitative differences were quite large in comparison.

From this experiment, using the three criterion measurements of slope, slope ratio, and variance accounted for by the linear component, there were no qualitative differences between the shape and conjunction conditions. Using the definition for unitization stated earlier - the no difference between two and one feature searches - this experiment offers tentative evidence for unitization.

Experiment 2 - Visual Search II

The 68% variance accounted for by the linear component found by Treisman and Gelade (1980) in the positive disjunction condition could be, as noted earlier, caused by a leveling off in reaction time (RT) for the 30 item display condition. If this is the case, then our experiment was not designed to test for this because it did not include a display condition larger than 15 items. In this experiment, the display size was increased to 30 items using the same subjects and the same procedure.

Method

The procedure here was exactly the same as in Experiment 1. The same subjects participated except for subject 2 who had previously dropped out. In this experiment, those subjects who were previously trained on green X's were again required to respond exclusively and positively to green X's and those previously trained on red T's in Experiment 1 responded positively to red T's here. The only difference was that, in addition to display sizes of 3, 6, or 15 items, a display size of 30 was included here. The number of trials within a block, 106 (10 practice), was kept the same such that each display size now consisted of 24 trials within a block. Each subject participated in 6 blocks for a total of 576 (636) trials. This experiment lasted approximately one hour.

Results and Discussion

There was no decrease in the variance accounted for by the linear component when the display size was increased to 30 items (see Figure 3 for a plot of RT x size). For the shape, the variance accounted for was .996 and .999 for the positive and negative functions, respectively, and for the conjunction it was .996 and .998. Again, the color condition was different for both. Variance accounted for on positive trials was .977 and for negative trials it was .196. It was interesting to note the subjects' experience. They were unaware afterwards that this experiment was any different from the previous experiment. Yet, their RT increased linearly with the 30 item display.

 Insert Figure 3 about here

This experiment did not find the leveling off in RT with increased display size that Treisman and Gelade (1980) found. The differences between our experiments and theirs may be due to their randomization method or, perhaps, some other factor not tested such as the different letter resolutions used in the two experiments.

Experiment 3 - Visual Search III

In the previous two experiments, all subjects had CM training and certain qualitative effects, such as serial versus parallel search, were hypothesized as a possible source of differences. Schneider and Shiffrin (1977; Schneider and Shiffrin, 1977) used the parallel versus serial distinction as one of several differences that exist between automatic processing and controlled processing. The serial-parallel distinction is not the only source of qualitative differences between the two modes of processing. Schneider and Shiffrin found that automatic processes are developed by CM training and controlled processes are maintained by VM training and that CM results were always quantitatively better than VM performance. Thus, one indication of the development of an automatic process is the presence of CM/VM differences. Schneider and Shiffrin also found a large reversal effect. If subjects were trained on a particular stimulus, and later, after the automatic process developed, that stimulus became a distractor, attention would be automatically allocated to the former target and performance would be impaired. Thus, another possible indication of the development of an automatic process is the reversal effect. This experiment incorporates these two new measurements, CM/VM differences and the reversal effect, to find evidence for automatic processing in the conjunction condition.

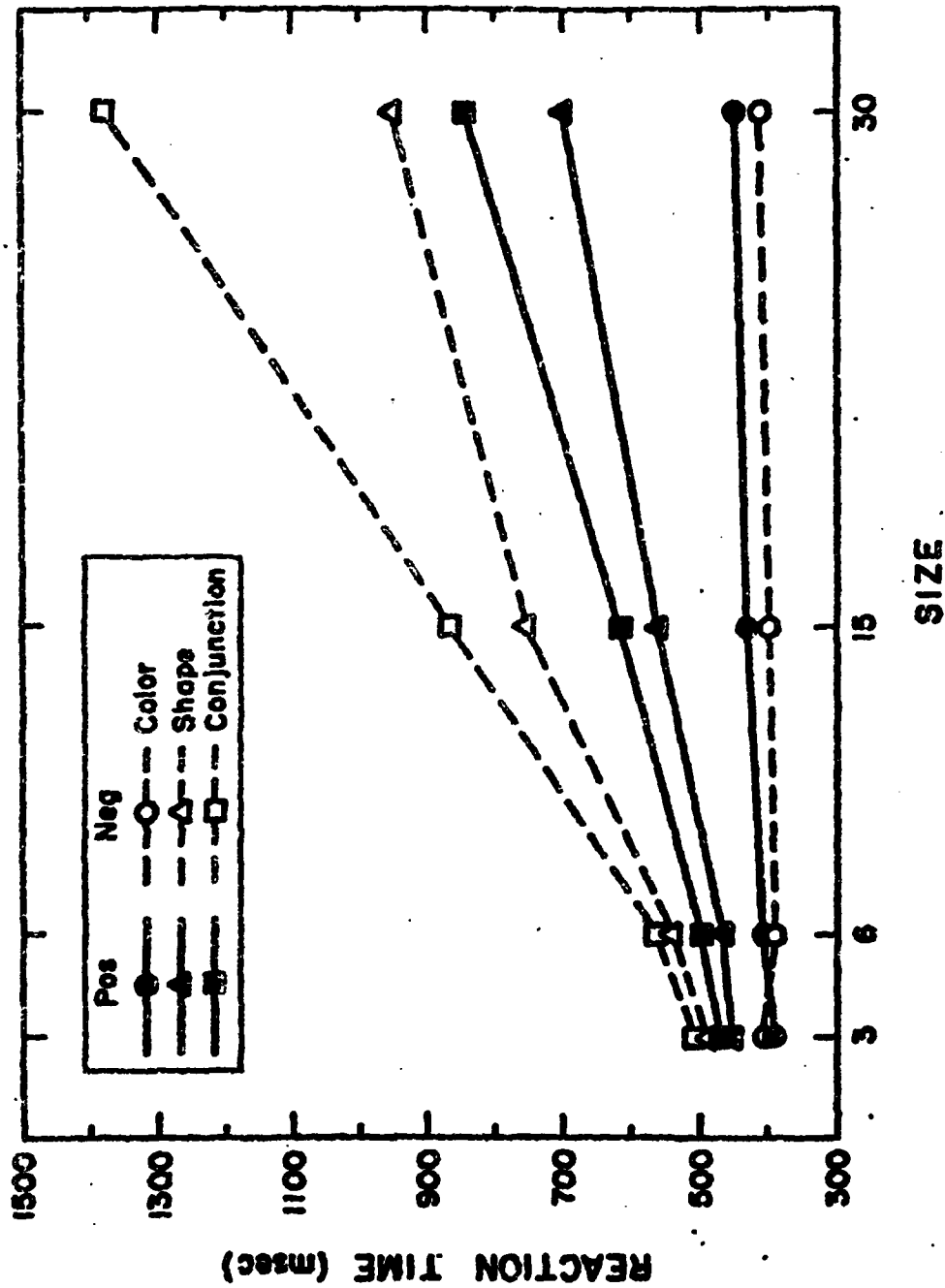


Figure 3. Data from Experiment 2: mean reaction times as a function of display size for positive and negative trials of the color, shape, and conjunction conditions.

Unitization is not synonymous with automatic processing. Because of the characteristics of automatic processing investigated by Schneider and Shiffrin and outlined in the introduction, automatic processing could not occur without unitization. Automatic processing is characterized by parallel search, albeit a nebulous term, and low load requirements. Thus if focal attention was required to conjoin two features as proposed by Treisman and Gelade (1980), then automatic processing could not occur. The two features would need to be unitized first.

Besides the new measurement techniques used in this experiment, to test the generalizability of the results of the previous experiments, the stimuli were changed in this experiment. The colors used, green and blue, were chosen to make the color discrimination harder and the letters used, X and O, were chosen to make the shape condition easier.

Method

Subjects. Eight University of Illinois undergraduate volunteers participated. All had normal or corrected-to-normal vision and were paid for their participation. None had participated in any of the previous experiments.

Apparatus and Stimuli. The same equipment was used as in the previous two experiments. The stimuli were blue and green X's and O's. Subjects were positioned so that the visual angles were the same as in the previous two experiments.

Procedure. The subjects were divided into two equal size groups, A and B. As in the previous experiment, a block of conjunction trials, a block of color trials, and a block of shape trials together will be termed a replication. Group A received 48 replications of CM training, a reversal condition of 10 replications, and then 48 replications of VM training. Group B received 48 replications of VM training, 48 replications of CM training, and then the 10 replications of the reversal condition.

The CM training condition was very similar to Experiment 1. Half the subjects had a blue O as the target and half the subjects had a green X as the target (the green X target conditions will be placed in parentheses for the following discussion). In the shape condition, the distractors were blue X's (green O's), in the color condition the distractors were green O's (blue X's), and in the conjunction condition the distractors were green O's and blue X's (blue X's and green O's). The number of display items - 3, 6, 15, or 30 - was a between block variable. On half the trials the target appeared (a positive trial) and on half the trials no target appeared (a negative trial). Subjects were to push one of two buttons depending on whether a target appeared or not. The button assignment was completely counterbalanced across conditions. All other aspects of the CM training condition were the same as Experiment 1.

In the VM training condition, any one of the four possible targets - green X, blue O, green O, or blue X - was randomly chosen and could appear on a positive trial. Depending on the block condition - color, shape, or conjunction - the appropriate distractors were chosen for the particular target. The distractors for the green X and blue O target were the same that appeared in the

CM condition outlined earlier. For the green O (blue X) target, the distractors in the shape condition were green X's (blue O's), in the color condition blue O's (green X's) and in the conjunction condition green X's and blue O's (green X's and blue O's). Thus, any particular stimulus could be a target on one trial and a distractor on the next trial.

In the reversal condition, the particular CM target for each subject had to be a distractor on each trial. Thus, if a subject was trained on a green X (blue O) target, the target in the shape condition would be a green O (blue X), and in the color condition the target would be a blue X (green O). In the conjunction condition the target was a green O (blue X) and the distractors were green X's and blue O's (green X's and blue O's).

Each block contained 106 trials (10 practice). Subjects had a total of 5088 CM trials, 5088 VM trials, and 1060 reversal trials in each of the three conditions. This experiment lasted approximately 25 hours.

Results

One of the subjects lost his glasses and couldn't complete the experiment on time. The slope results from the other 7 subjects are depicted in Figures 4 and 5.

Insert Figures 4 and 5 about here

A 5-way ANOVA (CM/VM X 3 conditions X 4 display sizes X positive/negative) with subjects as the random factor was used to analyze the RT data for the last 6 replications. The main effects of CM/VM manipulation [$F(1,6)=18.35$, $p<0.1$], stimulus condition [$F(2,12)=44.54$, $p<0.001$], size [$F(3,18)=36.26$, $p<0.001$], and positive/negative trials [$F(1,6)=12.37$, $p<0.05$] were all significant. The important twoway interactions of CM/VM X stimulus conditions [$F(2,12)=6.66$, $p<0.05$], CM/VM X size [$F(3,18)=20.88$, $p<0.001$], and stimulus condition X size [$F(2,12)=36.75$, $p<0.001$] were all significant.

Insert Tables 1 and 2 about here

See Table 1 for the beginning and ending slopes, positive to negative slope ratios, and variance accounted for by the linear component. Quantitative slope differences exist at all conditions for CM trained and VM trained stimuli. Similar to the previous experiments, the variance accounted for by the linear components was in the high 90's for the shape and conjunction conditions. In the reversal condition (see Table 2), positive conjunction slope increased from 6.78 msec/item in the last CM replications to 11.43 msec/item for the reversal. The slope was only slightly lower than initial CM performance of 11.19 msec/item. Negative conjunction slope also increased from 14.14 msec/item in the last CM replications to 20.30 msec/item for the reversal. This slope was also only slightly lower than the initial CM slope (20.67 msec/item). An increment also occurred in the shape condition due to reversal.

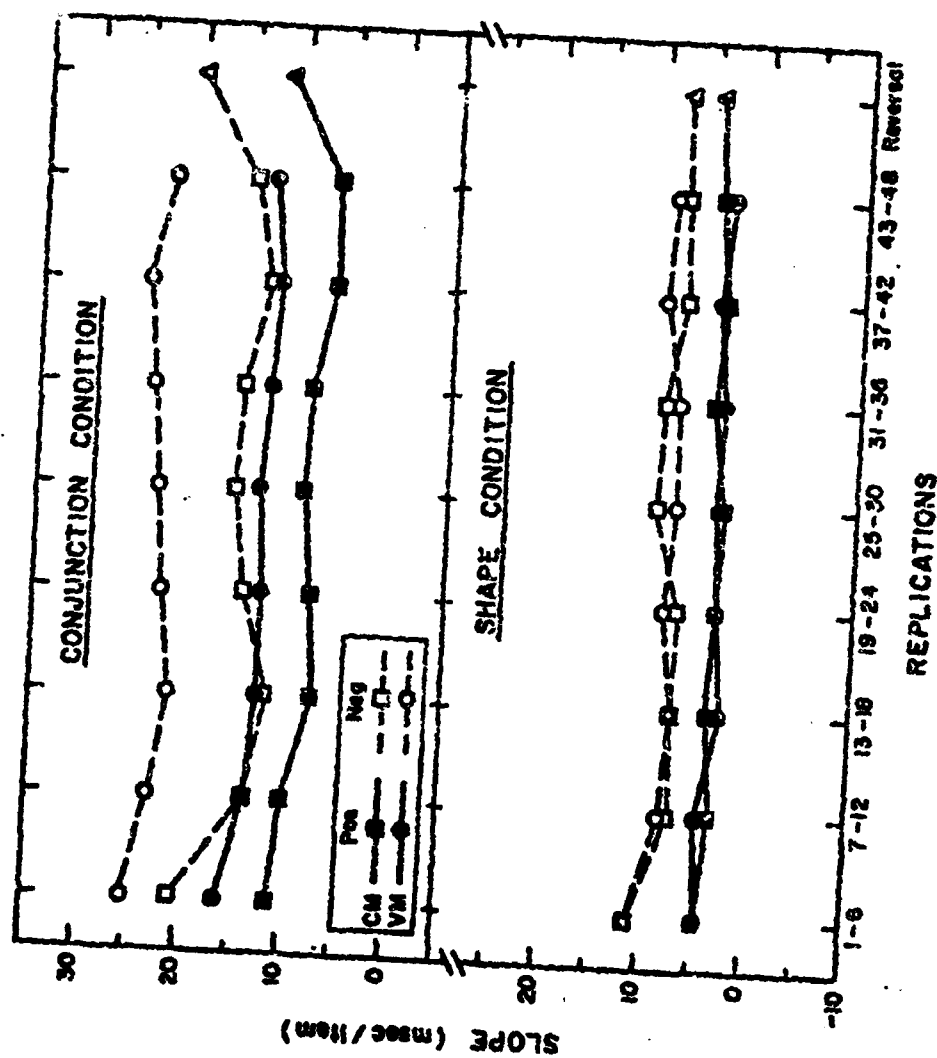


Figure 4. Data from Experiment 3; slopes across all replications. The CM and VM positive and negative slopes are plotted separately for the shape and conjunction conditions. Slopes from the reversal conditions, represented by triangles, for both conjunction and shape conditions are also plotted.

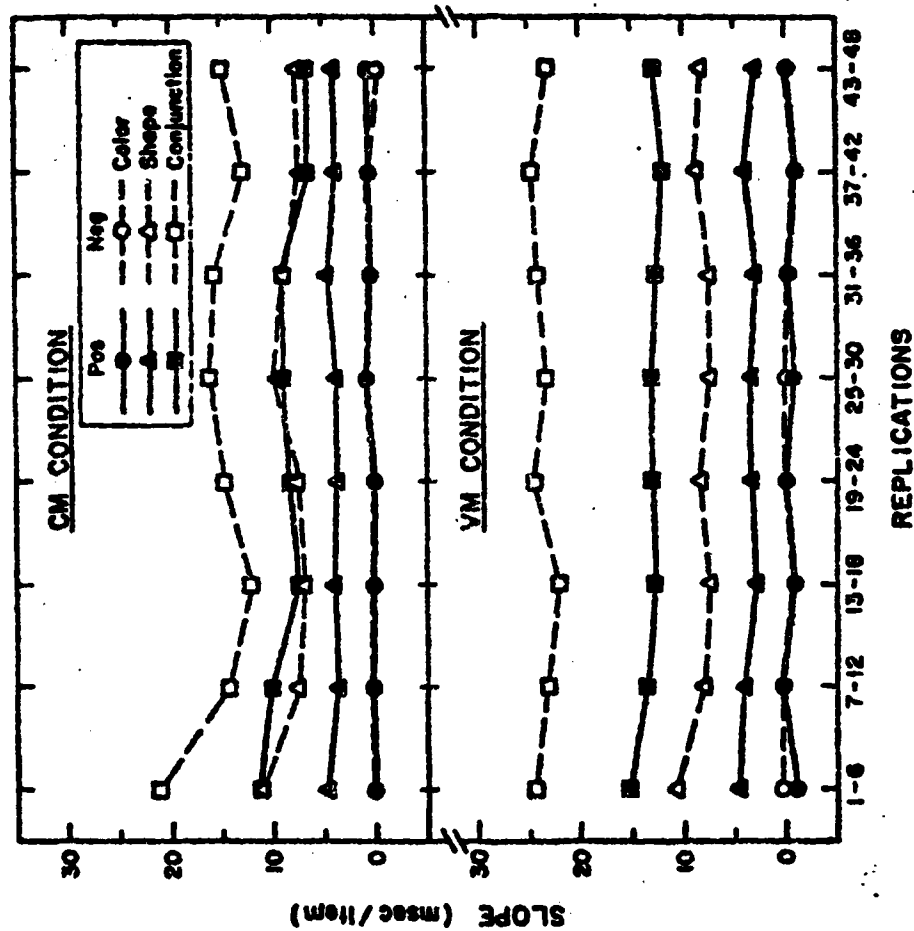


Figure 3. Data from Experiment 3: slopes across all replications. The positive and negative trials for color, shape, and conjunction conditions are plotted separately for the CM and VM conditions (the data are regressed from Figure 4 for convenience).

	Slope (First)	Slope (Last)	Slope Ratio (First)	Slope Ratio (Last)	Linear Component Variance (First)	Linear Component Variance (Last)
Color (+)	-0.05 (311)	0.77 (426)	-0.45	-2.48	.001	.553
(-)	0.11 (312)	-0.31 (430)			.031	.350
Shape (+)	4.46 (353)	3.99 (463)			.990	.994
(-)	10.95 (373)	7.27 (492)	0.41	0.55	.987	.995
Conj. (+)	11.19 (372)	6.78 (483)			.997	.998
(-)	20.67 (390)	14.14 (477)	0.54	0.48	.999	.998
Color (+)	-1.18 (356)	-0.02 (435)	-19.67	3.26	.657	.004
(-)	0.06 (343)	-0.38 (466)			.001	.406
Shape (+)	4.26 (638)	3.07 (532)			.971	.980
(-)	10.72 (640)	8.49 (543)	0.40	0.36	.994	.978
Conj. (+)	14.94 (596)	12.80 (486)			.996	.998
(-)	24.19 (661)	22.26 (490)	0.62	0.58	.998	1.00

Table 1. Data from Experiment 3: slopes, slope ratios, and the variances accounted for by the linear component for the first and the last 6 replications. The numbers in parentheses beside the slopes are the intercepts (in msec).

	Slope	Intercept
Color(+)	0.65	414
(-)	0.47	441
Shape(+)	4.42	519
(-)	7.68	575
Conj.(+)	11.43	554
(-)	20.30	596

Table 2. Slopes from the reversal condition from Experiment 3. The numbers in parentheses beside the slopes are the intercepts (in msec).

Discussion

Although different subjects participated in these two sets of experiments, when the two are compared this one was apparently easier than Experiment 1. The slopes started out lower and ended lower in the slope and conjunction conditions than in the previous experiments. Because the shape discrimination was made easier in this experiment, X's and O's compared to X's and T's previously, this lends further support to the conclusion from Experiment 1 that the conjunction performance is largely dependent on and similar to performance in the shape condition. As the shape condition becomes easier so does the conjunction condition. The positive to negative slope ratio of about 0.50 for the shape and conjunction conditions are very similar to that found in Experiment 1. Again there were no differences in the linear component for those two conditions.

The two new measurements used - CM/VM differences and reversal - both indicated that an automatic process had been developed in the CM condition to the conjunction stimulus. The ANOVA revealed quantitative differences between CM and VM performance as expected. In the reversal conjunction condition slopes were about equal to initial CM performance. So, it appears to be a fairly strong effect similar to what Schneider and Shiffrin found for their studies after the development of an automatic process. The reversal effect was not present for the color condition.

The type of training, CM or VM, does make a difference. In the conjunction condition especially, quantitative differences always existed. These differences were very small in the shape or color conditions. The VM positive conjunction performance had apparently asymptoted at 12.5 msec/item by replication 18 and further practice would not allow equal performance with the CM condition. All of these results taken together - similar shape and conjunction, CM/VM differences, and the reversal effect - indicate that an automatic process had developed in the CM conjunction condition and thus unitization of the two features had occurred.

Experiment 4 - Visual Search IV

This experiment was very similar to the previous experiment. A possible difference between the conjunction display and the single dimension displays could be the homogeneity. In the conjunction condition, distractors consisted of two possible stimuli. In the shape and color displays, the distractors are all the same stimulus; completely homogeneous. The homogeneity of the display would favor the shape and color conditions and thus possibly account for some of the quantitative differences between the shape and conjunction conditions. So, to make the conditions more similar, the shape and color distractors in this experiment also consisted of two possible stimuli. All other aspects of this experiment were the same as Experiment 3.

Method

Subjects. Four University of Illinois students volunteered. All were paid for their participation and none had served in any of the previous experiments. All had normal or corrected-to-normal vision.

Procedure. The procedure of this experiment was similar to group A in Experiment 3. Subjects participated in 48 replications of CM training, 10

replications of reversal and the 48 replications of VM training. Two of the subjects, because of scheduling conflicts, only participated in 18 replications of VM training.

The CM and VM conjunction conditions were exactly the same as Experiment 3. In the CM shape condition, distractors were green O's and blue O's (green X's and blue X's) for the green X (blue O) target. In the CM color condition, distractors were blue X's and O's (green X's and O's) for the green X (blue O) target. Similarly, in the VM training conditions, the target was chosen randomly from the four possibilities. Besides the two targets mentioned above, the blue X (green O) VM targets had distractors of blue and green O's (blue and green X's) in the shape condition and green X's and O's (blue X's and O's) in the color condition. The distractors in the reversal condition were also composed of the two possible stimuli. All other procedural aspects of this experiment were the same as Experiment 3.

Results

The results were very similar to Experiment 3 (see Figures 6 and 7). A 5-way ANOVA on replications 12-18 revealed very similar results. However, CM/VM differences were not significant [$F(1,3)=1.496$, $p=.31$] for a couple of reasons. First, the random factor, subjects, was quite small. Second, the analysis done was on replications 12-18 at relatively low practice. CM/VM differences might not have had a chance to develop by that time. Also, all subjects received CM training first so that VM performance was quite good initially because subjects had already familiarized themselves with the task and equipment. CM/VM differences should be significant, as in Experiment 2, if more subjects had been used and the order of training was counterbalanced.

Table 3 presents the starting and ending slopes for all the conditions, the positive to negative slope ratios, and the percent variance accounted for by the linear component. Results from the reversal condition are presented in Table 4. Again, the positive CM conjunction slope was relatively low at 7.9 msec/item. The characteristics of these results were very similar to Experiment 3.

Insert Tables 3 and 4 about here

Discussion

The similar results to Experiment 3 seems to suggest that the homogeneity of the display does not make much of a difference. Fewer subjects were used and the order of training was not counterbalanced so exact comparisons between the two experiments cannot be made. However, from these results, the effect due to homogeneity of the display should be very small.

Overall Discussion of the Visual Search Experiments

The shape and conjunction conditions did not seem to be qualitatively different from each other in any of the measurements used: slope, positive to negative slope ratio, and amount of variance accounted for by the linear component. Conjunction performance seemed to depend on the shape condition.

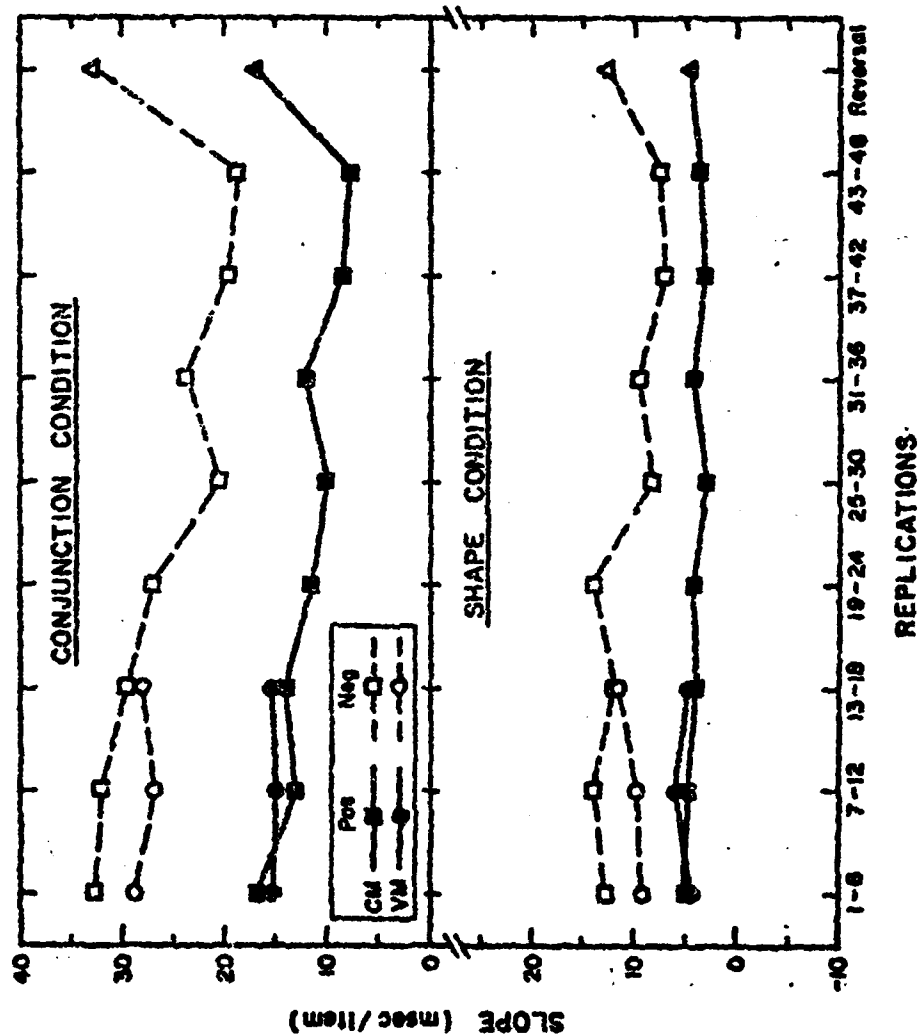


Figure 6. Data from Experiment 4; slopes across all replications. The CM and VM positive and negative slopes are plotted separately for the shape and conjunction conditions. Slopes from the reversal condition, represented by triangles, for both conjunction and shape conditions are also plotted.

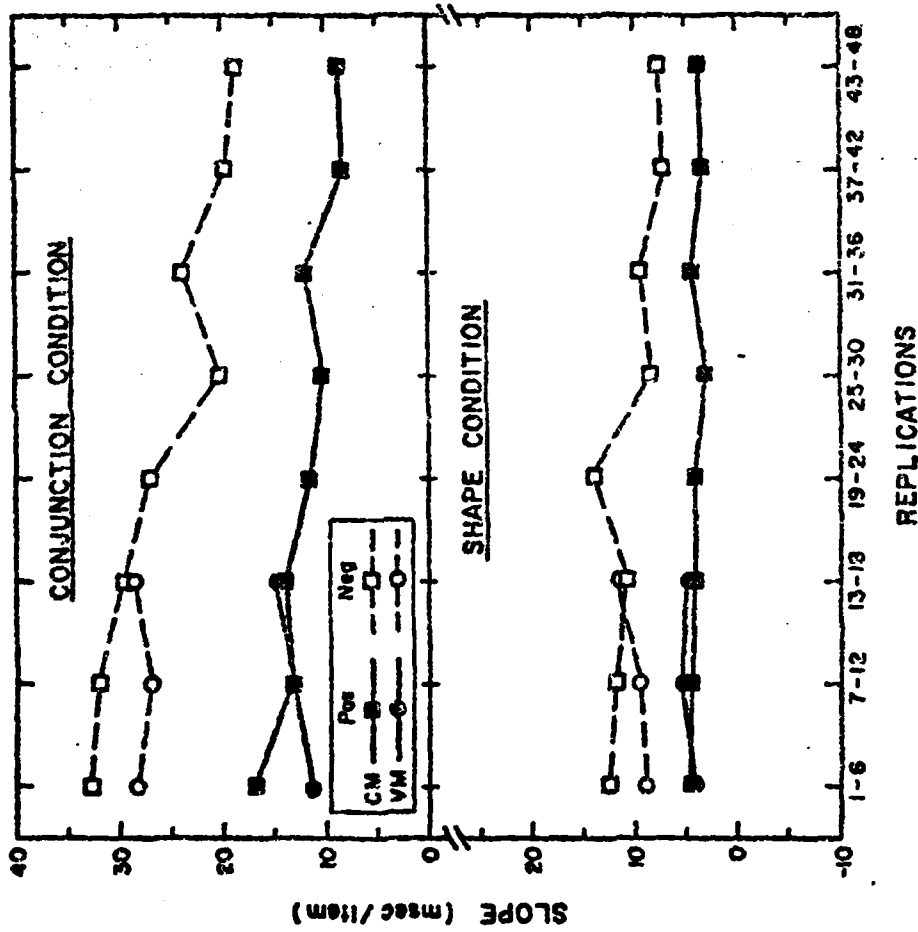


Figure 7. Data from Experiment 4: slopes across all replications. The positive and negative trials for the color, shape, and conjunction conditions are plotted separately for the CM and VM conditions. (The data are regressed from Figure 6 for convenience.)

	Slope (First)	Slope (Last)	Slope Ratio (First)	Slope Ratio (Last)	Linear Component Variance (First)	Linear Component Variance (Last)
Color (+)	1.11(517)	-0.35(431)	-5.84	0.92	.873	-.326
(-)	-0.19(511)	-0.38(435)			-.227	-.783
Shape (+)	4.86(601)	3.80(512)	0.38	0.50	.983	.994
(-)	12.82(649)	7.64(533)			.811	.999
Conj. (+)	16.73(694)	7.85(558)	0.51	0.62	1.00	.994
(-)	32.62(779)	18.71(588)			.999	.993
Color (+)	-0.71(528)	-1.11(527)	1.37	0.82	-.159	-.798
(-)	-0.52(533)	-1.35(521)			.612	-.973
Shape (+)	4.57(627)	4.91(558)	0.51	0.43	.916	.907
(-)	8.93(685)	11.39(577)			.989	1.00
Conj. (+)	15.28(697)	14.94(540)	0.54	0.51	.997	1.00
(-)	28.44(803)	28.48(576)			.998	.998

Table 3. Data from Experiment 4: slopes, slope ratios, and the variance accounted for by the linear component for the first and the last 6 replications. In the CM condition, the data are from replications 1-6 (first) and 43-48 (last); for the VM condition, the data are from replications 1-6 (first) and 1-6 (first) and 12-18 (last). The numbers in parentheses beside the slopes are the intercepts (in msec).

	Slope	Intercept
Color(+)	0.15	465
(-)	-0.76	474
Shape(+)	4.97	633
(-)	10.48	662
Conj.(+)	15.98	760
(-)	25.90	873

Table 4. Slopes from the reversal condition from Experiment 4. The numbers in parentheses beside the slopes are the intercepts (in msec).

The slope was relatively high if the shape discrimination was difficult as in Experiments 1 and 2. If the shape discrimination was made easier, as in Experiments 3 and 4, the conjunction slopes were much lower. These four experiments offer fairly good evidence for unitization of two features because the conjunction condition, which requires identification of two features, is not qualitatively different from the one feature search shape condition.

Experiments 3 and 4 indicated that an automatic process might have developed in the CM conjunction training condition. CM/VM differences existed in that condition and, similar to the Shiffrin and Schneider (1977) finding, the presence of a CM trained target as a distractor caused a fairly large decrement in performance. The automatic process tendencies is further indication of unitization; an automatic process could not occur if focal attention is needed to integrate the two features.

Although the slopes for the conjunction condition were quite low, the results still did not exhibit the classic parallel processing characteristics of 0 slope and positive to negative slope ratio of 1. The color condition always appeared to be searched in parallel. The conjunction condition, which requires both a color and a shape discrimination, cannot become any better than the worse of the two conditions. Both the shape and conjunction had lower slopes with continued practice. It is impossible to say at what slope a serial search can be called parallel. A much better approach is to compare the conjunction condition with a suitable control group, the shape condition, as was done.

One bothersome result did occur. It was surprising that the CM/VM manipulation did not have more of an effect. There were not CM/VM differences in the shape condition and, most disturbing of all, there did not seem to be qualitative differences between the VM conjunction and the VM shape. A further look at the CM and VM training methods is warranted.

In this kind of visual search task it is not really possible to have a truly consistent mapping if the shape and color conditions are indeed separable. As an example, if the target is a green X then: a) in the shape condition the color green appears; b) in the color condition the X appears as a distractor; and c) in the conjunction condition both shape and color appear as distractors. Although the two features conjoined together are never a distractor, the single features are. Therefore, before unitization, the mapping was not truly consistent. The inconsistency could have slowed the development of the automatic process. Another study done in our lab (Schneider and Fisk, 1980a) which studied the degree of consistency in the development of an automatic process, indicated that as the mapping becomes less consistent, the rate of development slows down. The next experiment tries to correct some of these problems.

Experiment 5 - Detection Task

Although the earlier experiments were fairly successful in showing unitization, several possible problems existed with those visual search experiments. First, the items in the display were possibly too close together. Eriksen and Eriksen (1974) found that there must be at least 1 degree of visual angle between the characters so that lateral masking has a low probability of

occurrence. As the display size increases, the probability that the target is masked laterally also increases. Thus, the longer RT's with increased display size could partly be due to lateral masking. Second, in the visual search experiments, the targets could occur at various foveal distances. The random placement should cancel out the differences but, it would be better to control for a possible effect. Third, the random placement of characters in the visual search experiment did not allow for a symmetrical display. Part of the search time by the subjects could have been taken to orient themselves to the display. The symmetry of the display would probably not matter in the color condition but the conditions for the development of a low slope in the shape and conjunction conditions might not be as favorable. Fourth, there was a noticeable loss of motivation in the visual search tasks as subjects practiced. A reaction time task, done for over 25 hours, becomes boring very shortly. The task must be challenging enough and experimenter controlled so that improvement occurs. Finally, the visual search experiments had the problem with the consistency of the mapping at the feature level which was discussed previously.

This experiment attempts to correct for the above problems. First, the items were arranged in a circle. All items were at the same foveal distance, the characters were equally spaced by at least 1 degree of visual angle, and the display was symmetric. Second, subjects were trained on the shape all at once, then the color, and finally the conjunction. Furthermore, subjects were trained on color splotches in the color condition instead of colored letters. This training method accomplishes several things: 1) the color of the CM conjunction targets will not be a distractor in the shape condition; 2) the shape of the CM conjunction target will not be a distractor in the color condition; and 3) only after sufficient practice on the single dimensions will the conjunction condition occur. In the conjunction condition, the separate shape and color features must be distractors. Only late in training will the CM training become relatively inconsistent. Finally, a multiple frame detection technique, similar to that used by Schneider and Shiffrin (1977), was used here. The continuous presentation of frames forces subjects to maintain attention to the display. Also, the experimenter has more control over the experiment by the ability to vary the difficulty of the task with the manipulation of the frame time. Variable difficulty stimulus conditions can be equalized by changing the frame time.

The visual search experiments recorded reaction time as the dependent variable. This experiment, being a detection task, used percent correct as the dependent variable. The same kind of qualitative differences were expected. The CM conjunction should not be qualitatively different from the CM shape or CM color. However, the VM conjunction should be qualitatively different from VM color and VM shape if, as hypothesized, the type of mapping does make a difference. This result was not found in the earlier visual search experiments which, it was argued, could be due to the inconsistency of the mapping. That problem was corrected in this experiment.

Method

Subjects. The eight subjects were undergraduate volunteers at the University of Illinois. All had normal or corrected-to-normal vision and were paid for their participation. None had participated in any of the previous

experiments.

Procedure. The display size was a between trial variable of three levels - 2, 4, or 6 items. Each item could appear in one of 12 positions in a circle with nearly constant radius. The display in each trial presentation was symmetrical. Thus, there were 6, 3, and 2 possible display configurations for the 2, 4, and 6 item conditions, respectively. Each letter subtended about .35 degrees of arc and appeared on a black background. The whole circle subtended about 2.3 x 2.1 degrees of arc with about 1.0 degrees of arc between characters in the 6 item condition.

The response was a two-choice reaction time task as in the preceding experiments. The target appeared on half the trials. In this experiment, however, a multiple frame procedure was incorporated (see Schneider and Shiffrin, 1977, Figure 2). Twelve frames would appear in rapid succession with characters appearing one after the other in the same positions depending on the display size. The target on a positive trial could appear only in frames 4-11 and the same character could not appear successively in the same position. The frame time, the time between onset of frames, depended on the stimulus condition. A block consisted of 82 trials of which the first 10 were considered practice and not analyzed. There were three stimulus conditions - shape, color, and conjunction - and two training procedures - CM or VM. A block of CM and VM trials together will be termed a replication. The type of mapping, CM or VM, was a between block variable.

Subjects participated in 10 replications of shape condition trials first. The stimuli were divided into two sets. Set A included the letters Z, Q, A, and V and set B included the letters K, V, S, and G. For the first 4 subjects set A was designated the CM set and set B was designated the VM set. The remaining subjects had the opposite set assignment. Each subject was assigned a letter and a color from the CM set that remained with him or her throughout the rest of the experiment. Subjects 1 and 2 had a blue V as a target, subjects 3 and 4 had a red A target, subjects 5 and 6 had a green S target, and subjects 7 and 8 had a yellow G target. In the CM condition, the CM target always remained the same while the distractors were randomly chosen from the VM set. The letter colors were always the same color as the CM target. In the VM condition, the target was randomly chosen from the 4 possible characters in the VM set. The VM distractors were chosen from the remaining VM letters. Again, the color of the characters was the same as the CM target color. Each frame stayed on for 100 msec with an interstimulus interval (ISI) of 50 msec for a total frame time of 150 msec. Training in this condition lasted about four hours.

Subjects were trained next in the color condition. In this part, color splotches were used instead of letters. The rub-out character on the color terminal, an oval shaped figure, was used because the brightness level was similar to that of the letters used previously. The target color was the same as the color of the CM target for each particular subject in the preceding experiment (see preceding paragraph). The distractors were chosen from the remaining three colors. The procedure was exactly the same as in the preceding part except colors were used and there was no VM condition. This was used primarily as a training exercise. This part consisted of a total of five blocks for a total of 360 (410) trials (practice trials are included in the total in

parentheses). This condition lasted about one hour.

Subjects next participated in the conjunction condition. This part of the experiment was very similar to the shape condition reported previously. The same letter sets for the CM and VM groups were used. The targets in the CM set for each particular subject remained the same as in the shape condition. Distractors, chosen from the VM set, could vary not only in shape as before, but in color also. Thus, distractors could be any of the four colors and any of the four VM letters. In the VM condition, the target was randomly chosen from the VM set. Distractors could be any color or VM letter with the constraint that a distractor could not be the same conjunction of color and letter as the VM target. Some CM targets were more difficult to detect than others. To try to eliminate floor and ceiling effects, frame times were tested by the following procedure:

- 1) Subjects were tested in the CM condition for 4 blocks at a frame time of 150 msec;
- 2) Subjects were tested in the CM and VM conditions for a total of 6 blocks (3 in each condition) at a frame time of 150 msec;
- 3) Subjects were tested in the CM condition for 6 blocks at a frame time of 200 msec;
- 4) Subjects were tested in the CM condition for 6 blocks at a frame time of 250 msec; and
- 5) Subjects were tested in the CM and VM conditions for a total of 22 blocks (11 blocks in each condition) at a frame time of 250 msec. This condition lasted approximately 8 hours.

Finally, subjects participated in a CM/VM color condition. This part of the experiment was exactly the same as the previous color condition except a VM condition was included here. The CM condition was exactly the same as previously. In the VM condition, the CM target color never appeared as a distractor or as a target. Because of the deletion of the CM target color as a usable color in the VM condition, a fifth color - magenta - was included in the VM set. VM targets were randomly chosen from the possible colors other than the CM color. The distractors consisted of the remaining three colors. This part consisted of 6 blocks (3 CM blocks and 3 VM blocks). The condition lasted for approximately one hour. For all conditions, a CM block and a VM block together will be called a replication.

Results

Two of the subjects, one due to illness and the other to scheduling conflicts, had to drop out of the experiment early. Their results were not included in the analysis. They were trained on the green Q and yellow G CM targets.

To get a measure of sensitivity, A' (Norman, 1964; Craig, 1979) was calculated. A' is a measure of the area under the ROC curve ranging from .5 for

chance detection to 1.0 for perfect detection. The A' measure is a somewhat more distribution free measure of detection sensitivity than d' , and seems a more appropriate measure when false alarm rates get very low as they do in this experiment.

Since each stimulus condition was run separately, 3-way ANOVA's (size x CM/VM manipulation x subjects) with subjects the random factor was performed on the A' data separately for the shape, conjunction, and color conditions. Prior to the ANOVA, an arcsin transform was performed on the A' scores. The shape condition was the first one subjects participated in. The ANOVA was run on replications 2-10. Each point represented 1296 observations. Both main effects of size [$F(2,10)=163.01$, $p<.00001$] and CM/VM manipulation [$F(1,5)=8.23$, $p<.05$] were significant. The interaction between these two factors was also significant [$F(2,10)=4.49$, $p<.05$].

All 11 replications were used in the analysis on the conjunction condition for a total of 1584 observations/point. The main effect of size was significant [$F(2,10)=53.73$, $p<.00001$]. The main effect of CM/VM manipulation [$F(1,5)=4.02$, $p=0.10$] and interaction of the two factors [$F(2,10)=2.57$, $p=0.13$] approached significance.

The color condition was the last run. All three replications were included in the analysis for a total of 432 observations/point. All effects were nonsignificant at the .05 level: size [$F(2,10)=2.06$], CM/VM manipulation [$F(1,5)=1.53$] and the interaction [$F(2,10)=0.16$].

Performance in the conjunction condition seemed to get worse with practice. The mean A' scores for the first and last replications are plotted in Figure 8 (each point represents 144 observations). In the CM condition for the 2 and 4 item displays performance decreased with time from .920 to .894 for the size 2 display and from .939 to .845 for the size 4 display. Performance improved from .778 to .844 for the 6 item display. The pattern was different for the VM condition. Performance either improved or remained constant from the first to the last replication on all size levels. The 2 item display was fairly constant, .876 to .874, from first to last. For the 4 item display performance improved from .775 to .848 and for the 6 item display performance improved from .695 to .761.

Insert Figure 8 about here

A 3-way ANOVA was run on the data from the first replication of the conjunction condition. The main effect of size was significant [$F(2,10)=4.76$, $p<.05$]. The main effect of CM/VM manipulation [$F(1,5)=5.01$, $p=0.03$] and the interaction of the two factors [$F(2,10)=2.95$, $p=0.10$] approached significance. The latter two effects were more significant than that found for the earlier analysis that was done on all 11 replications.

The nonsignificant effects in the color condition indicates again that this condition is different from either the shape or conjunction conditions. There were large effects of size for both shape and conjunction but no effect in the color conditions. The shape and conjunction conditions are plotted in Figure 9

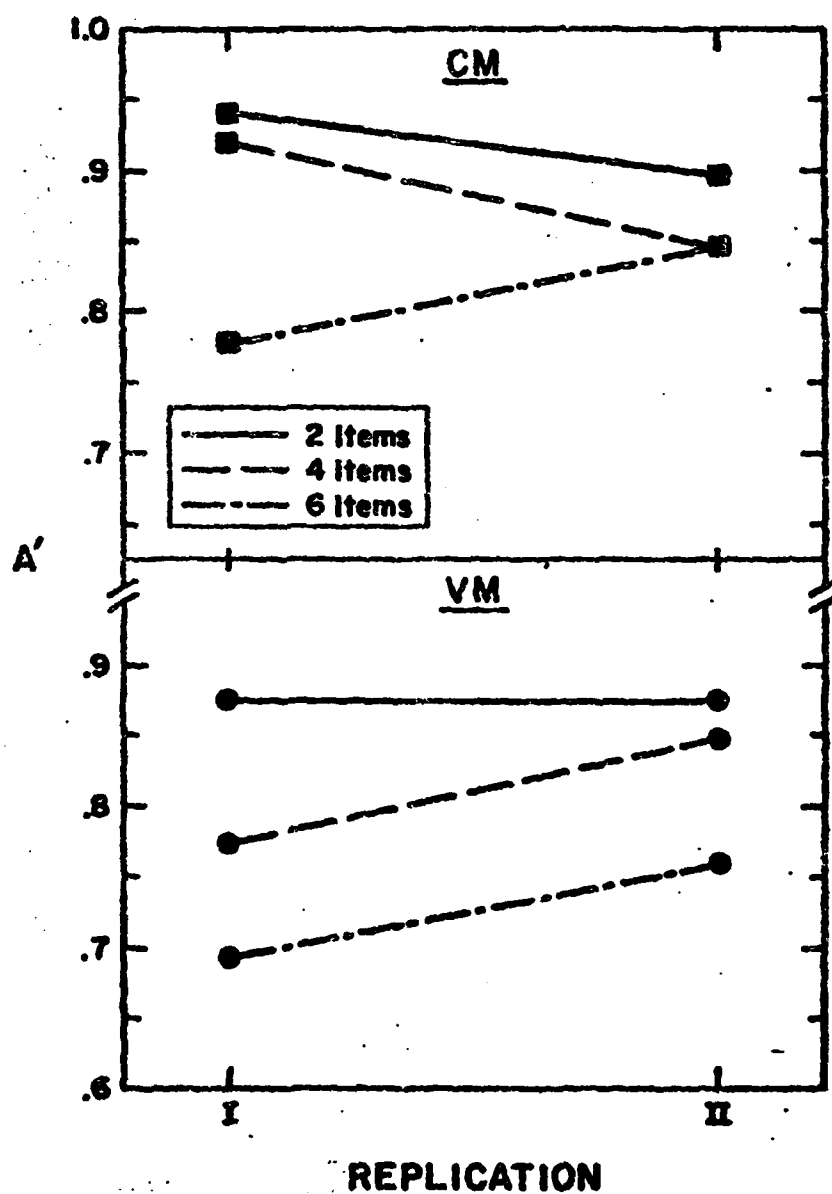


Figure 8. Data from Experiment 6 conjunction condition: mean A' scores for the 2, 4, and 6 item displays for the first (I) and last replication (II) are plotted separately for the CM and VM conditions.

so that a comparison can be made between the two. The points plotted for the conjunction condition are averaged from all 11 replications, 1584 observations/point. For the shape condition, the scores are averaged from replications 2-10; each point represents 1296 observations. In the plot of the CM conditions, the effects seem to be similar. Both shape and conjunction exhibit a decrement in performance as the display size is increased. In the VM graph, though, a slightly different picture emerges. The two conditions are about equal in performance for the 2 item size and diverge at the 6 item size.

Insert Figure 9 about here

Discussion

Even though the CM/VM manipulation and the interaction between mapping and size only approached significance for the conjunction condition, we believe that the effects are reliable for several reasons. First, the analysis used was quite conservative. The test did not take into account the number of observations for each data point which was over 264 for each subject in each condition. Instead, subjects was the random factor. Only six subjects were used so that the degrees of freedom were determined by the low number of subjects and not the relatively high number of observations. Second, depending on the particular CM target, performance was variable across subjects. In a multiple frame procedure where colors are temporally close together, false alarms occur especially for the secondary colors. Yellow was a particularly hard color to identify. If red and green distractors appeared in succession across a single channel, a false alarm was probable. Third, color was qualitatively different from the shape or conjunction condition. Because there were no significant differences for any of the factors or the interaction in the color condition, the color component in the conjunction condition most probably caused some variability. Because of these considerations, we place more importance on the marginally significant results in the conjunction condition.

Similar to the visual search experiments, the color condition was qualitatively different from the shape or conjunction conditions. In the color condition there was no effect of display size and the type of mapping, CM or VM, did not have an effect. Also similar to the visual search experiments, there were no apparent differences between the CM shape and CM conjunction conditions.

The interactions between size and CM/VM manipulation indicated that CM detection was qualitatively different from VM detection. Detection of CM items was affected more by the size of the display than was detection of VM items.

This experiment also supported the earlier conclusion of the importance of the type of mapping in the development of an automatic process or the unitization of features. Besides CM items being better identified than VM items for the shape and conjunction conditions, an important result was the tendency of the CM detection to become worse with practice. It was argued at the end of the last set of experiments that the inconsistency of the mapping could have impeded the development of an automatic detection. In this experiment, consistency was maintained at the feature level until the conjunction condition.

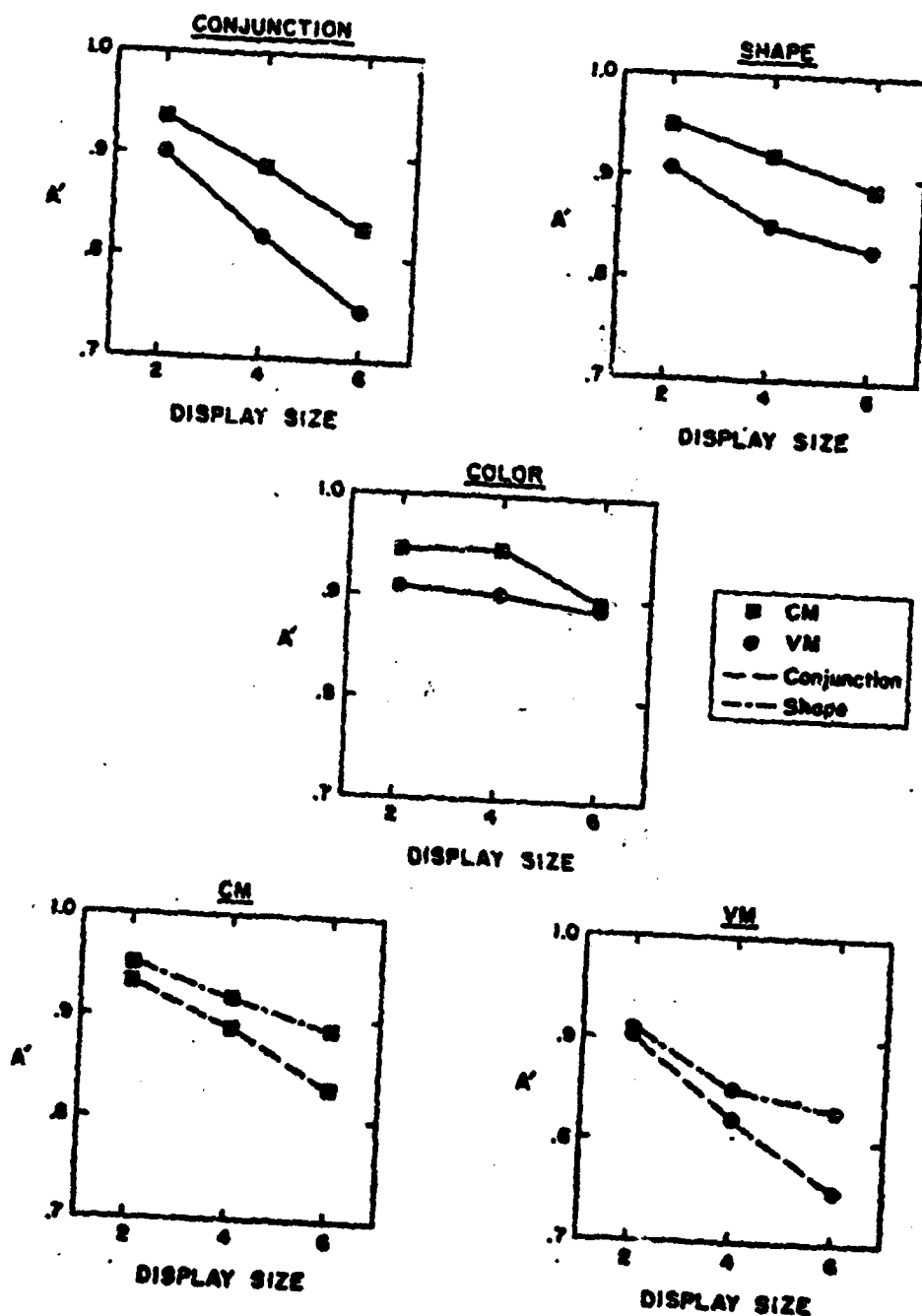


Figure 9. Data from Experiment 6: mean A' scores as a function of display size. CM and VM scores are plotted separately for the color, shape, and conjunction conditions. In the other two graphs, the shape and conjunction conditions are plotted together for the CM and VM conditions.

In that condition the target features, never conjoined but separate, occur as distractors. Therefore, the mapping cannot be consistent at the feature level. However, consistency was maintained at the higher conjunction level in the sense that the particular conjunction of features was always a target and never a distractor. When the first replication was compared with the last, performance declined in two of the three size conditions for the CM items. This decline cannot be attributed to an overall decrement in performance due to an unmanipulated factor such as motivation because the VM performance improved with time.

This experiment consolidated many of the previous hypotheses. Unlike the visual search experiments, there appeared to be qualitative differences between the VM shape and the VM conjunction conditions but no differences between the two when the mapping was consistent. If the definition for unitization depends on the equality of a single feature search with a conjunctive feature search, then the equality only occurs when the mapping is consistent. Also, it was found that the type of training, as hypothesized, was important. In this experiment, inconsistency only occurred in the conjunction condition. This inconsistent mapping affected the CM performance so that it actually got worse with practice. Again, there were no qualitative differences between the CM shape and CM conjunction conditions. This indicated that the features had become unitized. But, unitization is dependent on the proper kind of training.

Experiment 6 - Texture Segregation

This texture segregation experiment is similar to one used by Treisman and Gelade (1980). They hypothesize that texture segregation is pre-attentive and that fast segregation can occur only if it is possible to segregate on simple features and slow segregation will occur if focal attention, which is not pre-attentive, is needed to segregate two textures. They found that color and shape feature segregations were faster than conjunction segregation in a card-sorting task.

Schneider and Shiffrin (1977; Shiffrin and Schneider, 1977) found that CM targets would subjectively "pop out" after extensive training. One subject reported that he had trouble reading for a few hours after participating in the experiment. Possibly, if subjects were trained on CM targets in a search task and then run in a texture segregation experiment where CM targets were on one side of the boundary, that side might subjectively "pop out" making the task simpler.

The same subjects who participated in Experiment 1 performed in this task. They had already had extensive practice searching for a particular stimulus. In the conjunction condition of the texture segregation there are four possible stimuli. The boundary is not determined by color or shape alone but by a conjunction of a color feature and a shape feature. Two different stimuli appear on each side of the boundary. Thus, subjects had only been trained on one of the two stimuli that made up a side. Therefore, halfway through the experiment, subjects were CM trained on the other stimulus and performance in the conjunction texture segregation task was evaluated.

Method

Stimuli. The stimuli were the same as in Experiment 1: green X's and T's and red X's and T's.

The display consisted of a 5 x 5 matrix which subtended about 3 x 4 degrees of arc. There were three conditions which varied across blocks of 106 trials:

- 1) Shape--one side consisted of green and red X's and the other side consisted of green and red T's;
- 2) Color--one side consisted of green X's and T's and the other side consisted of red X's and T's;
- 3) Conjunction--one side consisted of green X's and red T's and the other side consisted of red X's and green T's.

The matrix was divided into two sides either horizontally or vertically so that a horizontal or vertical line could be pictured as dividing the matrix into its two sides. In the horizontal condition, the middle row was randomly chosen to contain the same items as the row above or below the middle. Likewise, in the vertical condition, the middle column was randomly chosen to contain the same items as the column to the left or right of the middle. For each side and for each condition (shape, color, or conjunction), each of the 25 items was randomly chosen from the two possible choices.

Subjects. The same subjects who participated in Experiment 1 participated in this experiment.

Apparatus. The same equipment was used.

Procedure. The procedure was similar to Experiment 1. Those subjects who had pushed the left button if a target appeared, now pushed the same button if the dividing line was horizontal. The other button was pushed if the dividing line was vertical. The subjects who had the opposite button assignment in Experiment 1, again had the opposite assignment in this experiment.

Each trial consisted of the following series of events. The words "SIDE 1" and "SIDE 2" in white letters, with the corresponding colored letters for each condition underneath, appeared at the very top of the screen for a maximum of 30 seconds or until both subjects initiated the trial by pushing a button with the non-dominant hand on a separate response box. A fixation dot appeared in the middle of the screen. Then, 500 msec later, the display came on replacing the fixation dot. The display terminated as soon as both subjects responded or after 4 seconds. Immediate feedback was given to the subject making an error by turning on a red light on the response box and sounding a tone on the subject's headset.

The blocks of 106 trials were randomly permuted so that subjects were exposed to an equal number of blocks of each condition. The first 10 trials of each block were considered practice and deleted. Subjects were run in sessions which lasted 50 minutes.

Three blocks of shape, color and conjunction will be termed a replication. Subjects participated in 15 replications for a total of 45 blocks. This part of the experiment lasted about six hours.

After this initial texture segregation part, subjects were trained on another CM target under 2 kinds of conditions: 1) a new target condition similar to Experiment 1 except with a different target; and 2) a two target condition where subjects were to search for two conjunction targets. Conjunction texture segregation was evaluated during this training.

The two target condition. In this conjunction condition subjects were required to search for one of two targets, either a red T or green X. On one-fourth of the trials, a red T appeared in the display, on one-fourth of the trials a green X appeared, and on the remaining half no target appeared. Subjects retained the same hand to button assignment. The task again was to decide either that one of the targets was present or that no target appeared. At the beginning of a trial, this two target condition was specified by having both a green X and red T appear underneath the word "Targets". The distractors remained the same as the conjunction condition of Experiment 1.

The new target condition. In this condition, subjects who had previously been trained to respond to green X's were now trained on red T's and vice versa. All aspects of this procedure were the same as that reported in the conjunction condition of Experiment 1.

The order of the conditions was as follows. The experiment consisted of 4 conditions each constituting a block of trials: texture segregation (as in Experiment 2), old target condition, new target condition, and two target condition. Each block consisted of 106 trials of which the first 10 trials were considered practice and deleted. A replication consisted of 6 blocks: 3 blocks of the two target condition, and 1 block each of old target, new target, and conjunction texture segregation. The shape and color texture segregation conditions were not included in this part of the experiment. The order of the blocks was randomly permuted within each replication. An experimental session always lasted about 50 minutes. The five subjects participated in 12 replications altogether which lasted about eight hours.

Results

The means of the RT's for the five subjects are plotted in Figure 10. Each point represents 576 observations. In the first 15 replications, there were large practice effects for all conditions. In the conjunction condition, the first block RT is off the graph. Subjects could not understand how to find the boundary and could not respond within the four seconds given. The mean RT by the fifteenth replication was 880 msec. In the shape condition subjects started with a mean of 970 msec and ended with a mean of 510 msec. In the color condition, subjects' RT improved from 740 msec to 450 msec. The mean RT for the conjunction condition in the fifteenth replication is better than the mean RT in the shape condition for replication 1.

Insert Figure 10 about here

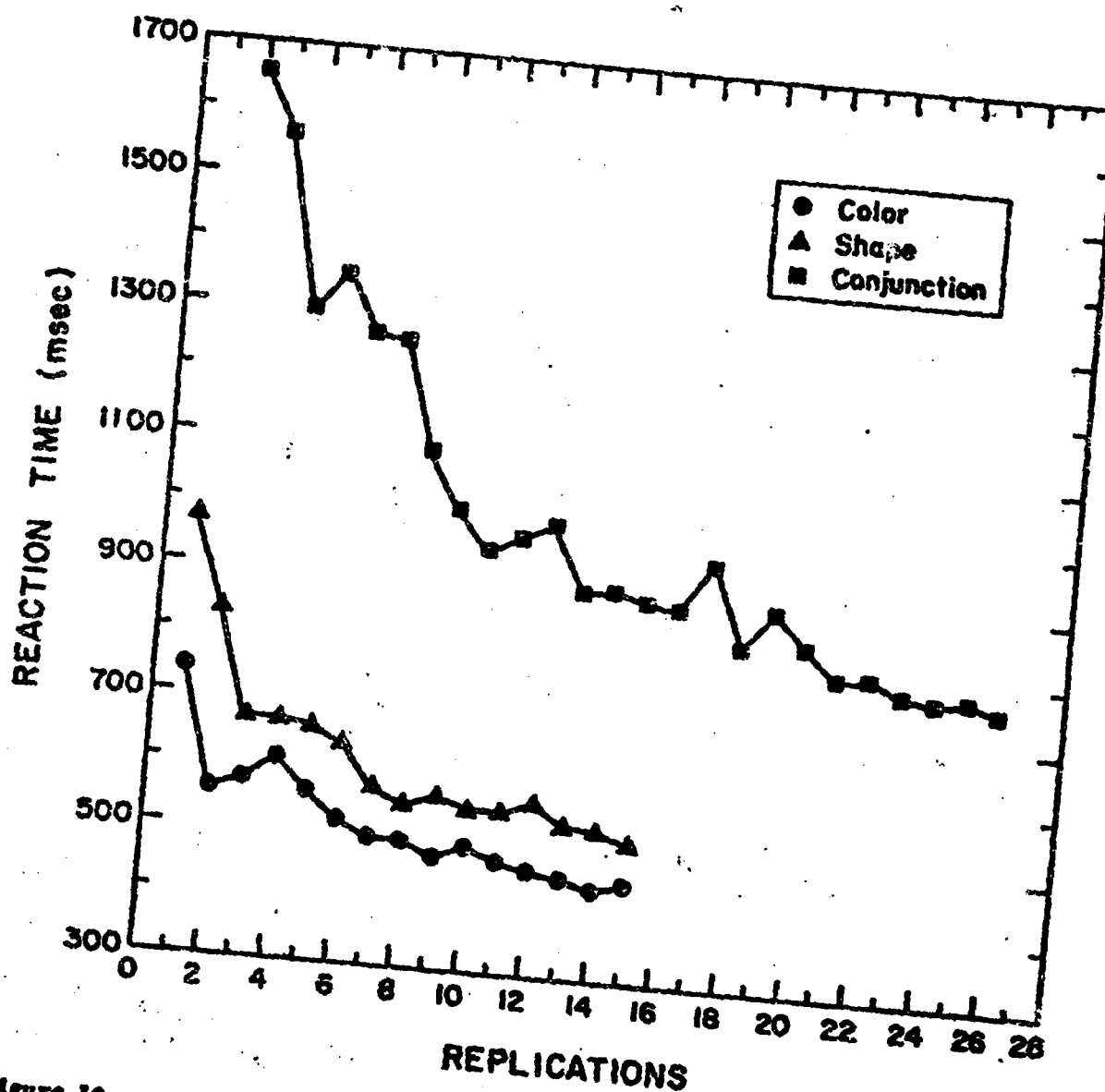


Figure 10. Data from Experiment 7: mean reaction times for correct responses as a function of practice. For the first 15 replications, data were collected for color, shape, and conjunction texture segregations. Starting with replication 16, subjects were trained on the new target and tested for the conjunction texture segregation only.

The conjunction RT is approximately equal to the shape RT plus the color RT. In the first 8 replications RT (conjunction) is greater than the RT (shape) plus the RT (color). For the last five replications RT (conjunction) is less than RT (shape) plus RT (color). The sum of the two single feature conditions does include an extra response time.

In the second twelve replications, subjects were concurrently trained on the new target. Performance started to level off for the last three replications before this new training. After this further training, there was a noticeable improvement in RT and, having started with a mean of 880 msec, by the last replication the mean was 760 msec. This was almost as good as the initial color condition mean of 740 msec.

In Figure 11 the old, new, and two target conditions are compared. The mean RT for replications 9-12 are plotted so that each point represents 576 observations. The slopes for the positive conjunction trials were 14.79 msec/item, 20.92 msec/item, and 31.53 msec/item for the old, new, and two target conditions, respectively. For the negative conjunction condition, the slopes were 40.59 msec/item, 38.77 msec/item, and 65.09 msec/item for the old, new, and two target conditions.

Insert Figure 11 about here

Discussion

Searching for two targets takes more time than searching for one target. When the slopes for the old and new target conditions are added together, that sum is greater than the slope for the two target condition. Thus, if each comparison takes a certain time, a two target search is faster than expected on the basis of the results from the two single target conditions. If the search was done completely in parallel, memory set size should not have an effect as it does in this experiment. These results indicate that the joint search had not been fully unitized.

Performance in the conjunction texture segregation condition never became as good as that in the shape or color alone. The mean RT for conjunction in the last replication was much better than initial shape performance and almost as good as initial color performance. The conjunction condition was within range of what could be expected if the two color components are added together and a response time is subtracted. The training on the new target did have an effect on conjunction performance. After an apparent asymptote in performance by the fifteenth replication, there was a 220 msec improvement after the new training. This suggests that the CM target side becomes easier to segregate.

There is a major problem of scaling complexity in this kind of experiment. We can assume that the three features have different saliences with the color strong, the shape mild, and the conjunction weak. If this is the case then: 1) color segregation has one strong feature that will determine the boundary and a mild and weak feature that crosses the boundary; 2) shape segregation has one mild feature that will determine the boundary and a strong and weak feature that crosses the boundary; and 3) conjunction segregation has one weak feature that

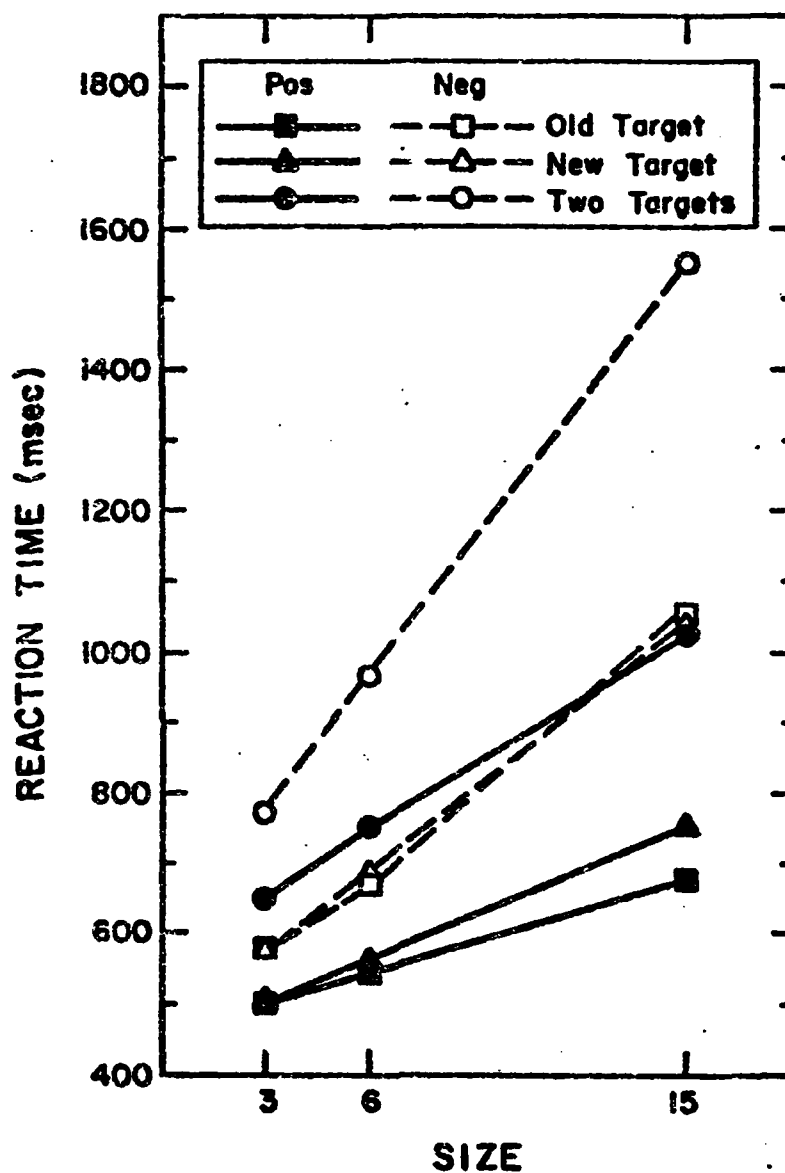


Figure 11. Data from Experiment 7: mean reaction times for correct responses as a function of display size. Positive and negative trials for the new, old, and two target conditions are graphed.

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will determine the boundary and a strong and mild feature that crosses the boundary. Certainly subjects had a great deal more nonlaboratory experience segregating reds and greens and T's and X's rather than red T's and green X's. Had we had the equipment to weaken the color and shape salience by using less discriminable colors and shapes, the quantitative differences between the conditions would probably be much less.

In the conjunction condition, the target side of the display probably did not subjectively "pop out" even after practice. The subjective feeling of characters popping out of the display is probably caused by the automatic grabbing of attention. If attention is grabbed by many sources then the process would probably abort. The more salient target would probably grab all the attentional resources. In this experiment 10 or 15 items would have to grab the attentional resources which would probably cause an overload in the automatic process.

The present results provide no indication that the conjunction texture segregation is qualitatively different from the color or shape segregation. It is certainly weaker and needs more training, but this is to be expected. We did show that with enough practice the conjunction condition approaches performance in the color and shape conditions.

Experiment 7 - Integrality Tests

A distinction is made between separable and integral dimensions. We have been studying the shape and color dimensions which have been characterized as separable by earlier researchers (Handel and Imai, 1972; Gottwald and Garner, 1975). Treisman and Gelade (1980) also used the shape and color dimensions in their feature tests. They proposed that further distinguishing characteristics of the two types of dimensions could be made by employing their feature tests: separable dimensions require focal attention to integrate two features while features from integral dimensions do not require the focal attention. It could be possible that the dimensional structure might change as the features become unitized with practice.

Shepard (1964) articulated the difference between what he calls analyzable and unanalyzable dimensions. Using multidimensional scaling techniques, he found that a city-block metric fit the data best for analyzable dimensions and a Euclidean metric was best for unanalyzable dimensions. Several other investigators (Hyman and Well, 1967, 1968; Handel and Imai, 1972) extended the stimulus set and found similar results across several different kinds of dimensions.

Garner (1970, 1974a) distinguished between separable and integral dimensions. He found that integral dimensions exhibit a redundancy gain and interference due to selective attention while separable dimensions have no redundancy gain and no interference due to selective attention. The concept has had a wide range of application. Recently, developmental differences have been explained by postulating the saliency of the dimensional structure during different periods of development (Kemler and Smith, 1978; Smith and Kemler, 1977, 1978; Shepp and Swartz, 1976).

In this experiment, the subjects from Experiment 3 were tested at certain times during training. The integrality-separability tests were similar to the ones used by Garner (1977). Specifically, the tests were designed to determine a redundancy gain and selective attention effects if they exist. If there is a redundancy gain and selective attention deficit in comparison to the uni-dimensional conditions, then those dimensions are characterized as integral. If there is no effect then the dimensions are characterized as separable. By testing at certain times during the development of an automatic process, it will be determined if the dimensional structure changes with practice and the type of training.

Method

This experiment was run in conjunction with Experiment 3 so that the same equipment and subjects were used.

The same four stimuli used in Experiment 3 were used: green and blue X's and O's. There were eight possible conditions (see Table 5). In the uni-dimensional conditions, discrimination could be made by shape or color alone; in the redundant conditions, discrimination could be made on the basis of either shape or color; and in the classification condition, discrimination could be made by color or shape alone while the other dimension varied.

At the start of a trial in the uni-dimensional and redundant conditions, the two stimuli would appear at the top of the screen one to the left and one to the right (e.g., green T on the left and green X on the right in the shape condition). For the selective attention classification conditions, four stimuli would appear at the top of the screen two on the left and two on the right (e.g., on the left would be a green X with a green T underneath and on the right would be a blue X with a blue T underneath for the color classification condition). This initial frame will be called the orientation frame. After subjects had studied this frame, the trial could be initiated by pushing a button with the left index finger. Immediately after both subjects pushed the initiation button or after 30 seconds, a focus dot appeared in the middle of the screen. After 500 msec, the probe item replaced the focus dot. The probe item could be one of the stimuli that appeared on the orientation frame previously. If the probe item was a character that appeared on the right in the orientation frame, subjects were to push the right button with the middle finger of their right hand. If the probe item was a character that appeared on the left in the orientation frame, subjects were to push the left button with the index finger of their right hand. After each subject responded, the orientation frame for the next trial appeared. If a subject made an error, a tone sounded over the subject's headset and a red light on the response box turned on. The feedback remained on until initiation of the next trial. Subjects were instructed to respond as fast as possible without making mistakes.

The right-left occurrence of stimuli in the orientation frame and the use of stimuli as probe items within a condition was completely counterbalanced. A block consisted of 20 trials. The 8 stimulus conditions mentioned above were manipulated between blocks. A test consisted of 80 blocks of trials (10 replications of each stimulus condition). The order of occurrence of the blocks was randomized within groups of 16.

Subjects from Experiment 3 were tested preceding, in the middle, and following that experiment. Thus, this experiment consisted of three 80 block tests. The middle test occurred before the reversal condition and after group A had CM training and group B had CM training in Experiment 3. This second test will be called a CM test for group A and a VM test for group B. The third test occurred before the reversal condition and after group A had VM training and group B had VM training in Experiment 3. This third test will be called a VM test for group A and a CM test for group B. Each test lasted about one hour and 30 minutes.

Results

The mean RT's are presented in Figure 12. In the top half of Figure 12, the two color conditions were averaged together to yield the uni-dimensional score, the two redundancy means were averaged to yield the redundancy score, and the color classification mean was graphed. In the bottom half of Figure 12, the two shape conditions were averaged together, the redundancy score was the same as in the top part, and the score from the shape classification was graphed.

 Insert Figure 12 about here

Three-way repeated measures ANOVA'S (3 tests X 3 stimulus conditions X 7 subjects) with subjects as the random factor were run on both the color and shape RT's (the RT's presented in the top and bottom parts of Figure 12, respectively). For the color RT's, the main effect of tests was significant [$F(2,6)=21.73$, $p<.001$]. As can be seen from Figure 12, this effect is due primarily to the differences between the first test and the CM and VM tests combined; there is no difference between the CM and VM tests. There was not a significant redundancy gain or deficit due to selective attention interference because the stimulus condition main effect was nonsignificant [$F(2,12)=2.09$] at the .05 level. The interaction between tests and stimulus conditions was also nonsignificant [$F(4,24)=0.46$]. For the shape analysis, there was also a significant main effect of tests [$F(2,6)=19.65$, $p<.001$]. For the shape, there was a significant main effect of stimulus condition [$F(2,12)=10.34$, $p<.01$]. The interaction between tests and stimulus conditions was nonsignificant [$F(4,24)=0.79$].

Discussion

The interesting result was the lack of an interaction between the tests and the stimulus conditions. This result implies that there is no change in the dimensional structure with practice or a particular kind of training (i.e., CM or VM training). Thus, for the color conditions which yield the classic separable results, that separability does not change to integrality. Similarly, for the shape condition, integrality does not change to separability with training. The unitization of features with practice implied by the results from Experiment 3 does not necessarily mean that the dimensional structure changes. Unitization is not the same as dimensions becoming more integral; the former deals with just two features while the latter is concerned with the whole dimensional structure.

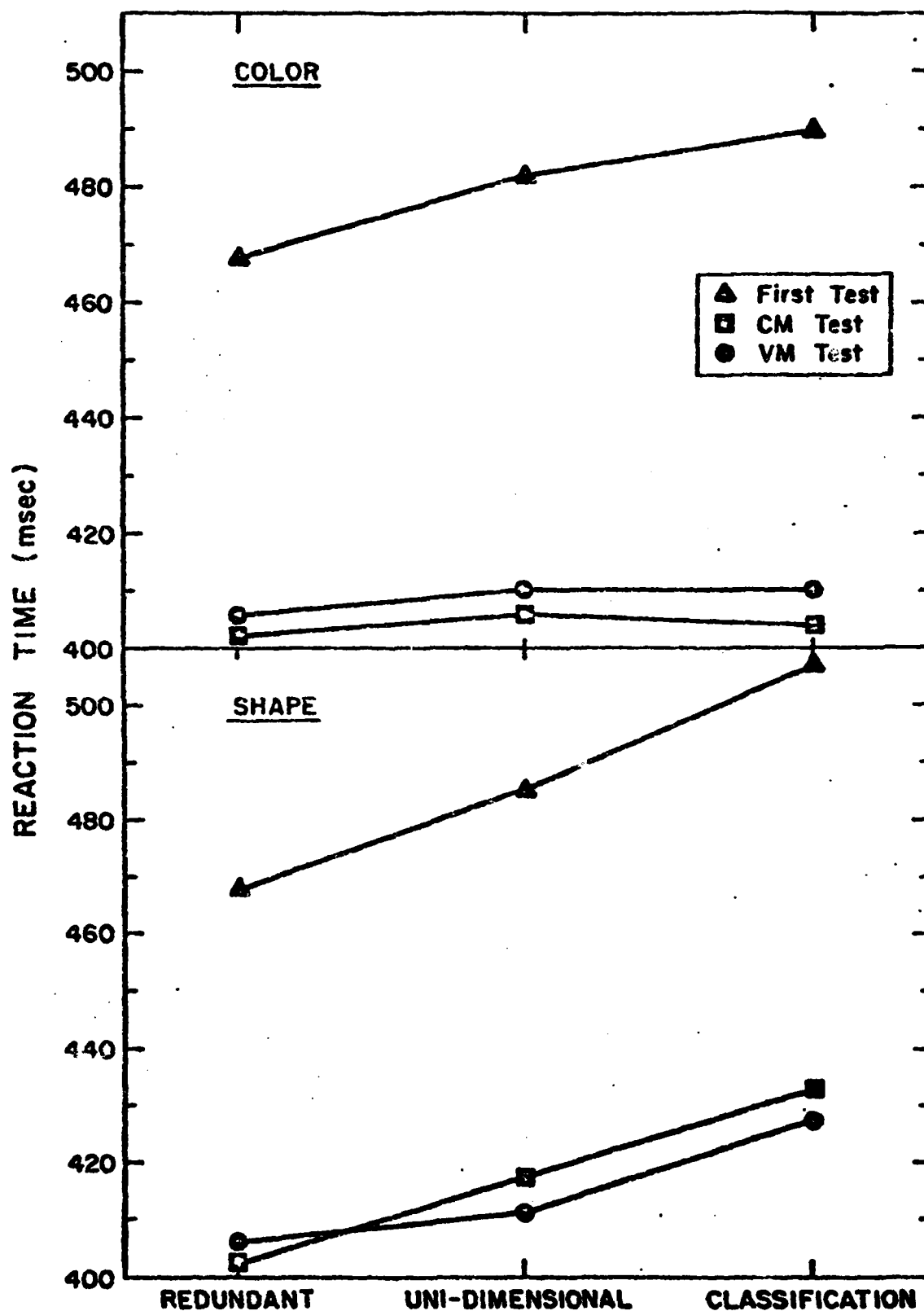


Figure 12. Data from Experiment 8: mean reaction times for correct responses as a function of the kind of test. The first, CM, and VM tests are plotted separately for the color and shape discriminations.

The nonsignificant main effect for the stimulus conditions in the color analysis and the significant main effect for the same factor in the shape analysis is a curious result. This implies that the color dimension is separable and the shape dimension is integral. The two dimensions together should be separable or integral and should not display tendencies of both kinds of structures. Gottwald and Garner (1972) using different shapes, colors, and tasks classified the shape-color dimensions as separable and did not find any ambivalence in their results. However, Garner and Felfoldy (1970) found similar ambivalent results when they analyzed the size x angle dimensions. A possible difference between our results and the Gottwald and Garner (1972) results is that we used an RT task and they used a card-sorting task. RT is a more sensitive measure than card-sorting. If dimensions are hypothesized as separable, then the null hypothesis must be accepted. The main problem with accepting the null hypothesis is that the task might not be sensitive enough to reject it. Another possible difference is that subjects in the Garner card-sorting experiments were instructed to sort in the redundant conditions either by shape or color. We did not give such instructions in our RT tasks in the redundant condition so that discrimination could be done by the faster factor of the two dimensions. It might be unfair to compare the shape uni-dimensional condition with the redundant condition which could be done by the faster color discrimination. Yet, this possibility does not explain the deficit due to selective attention in the classification condition for the shape (427 msec to 411 msec in the uni-dimensional task for the CM test).

It is not necessarily surprising that there were no CM/VM differences in this experiment. Subjects had only been CM trained on one of the possible four stimuli yet, in this experiment, subjects had to respond to all four stimuli. The CM test was not a CM condition (there were no distractors in this task) and was used to reflect any dimensional changes that might occur with a particular type of training.

Dimensional structure seemed to be fairly invariant with practice. It was not invariant with task, though. Using a sensitive RT task as used here, the shape-color dimensions, which were found to be separable by Gottwald and Garner (1972), displayed integral tendencies in this experiment. When the first test of the color condition is analyzed alone, the main effect of stimulus condition approaches significance also [$F(2,12)=2.75$, $p<.10$]. The use of a card-sorting task could be misleading if the acceptance of the null hypothesis is a major tenet of a theory.

Overall Discussion and Conclusions

An automatic process was apparently developed in the conjunction condition of the visual search experiments. The results satisfied many of the criteria for an automatic process as defined by Schneider and Shiffrin (1977; Shiffrin and Schneider, 1977): 1) there were CM/VM differences; 2) there was a reversal effect - it was difficult to suppress or ignore the CM target; and 3) the conjunction condition had a relatively low slope - it was fairly resistant to noise.

The lack of inconsistencies at the feature level slowed the development and reduced the effectiveness of automatic processing. In order to develop

automatic processing for conjunctions we sequenced the training (Experiment 6) so an automatic detection response would develop for each feature before beginning training of conjunction search. Other experiments have shown (Schneider and Fisk, 1980a) that if a stimulus occurs as a target and a distractor (in a multiple frame paradigm being a distractor about twice as often as being a target) no automatic processing develops. While developing a conjunction detector it seems reasonable that the subject searches for one feature then a second. Since each feature appears as a distractor stimulus much more often than it appears as a target, these feature inconsistencies would inhibit or preclude the development of automatic processing while training in the conjunction search condition. In order to develop a conjunction detector it may be necessary to train subjects in conditions where the two features are positively correlated across the stimulus set. It should be noted that in nonlaboratory environments conjunction detectors probably develop more easily than in the present experimental paradigm. In the present experiments the elemental features were highly negatively correlated ($r = -.93$) in the conjunction search conditions. Features which appear in important conjunctions (e.g., face shape and skin color) in natural environments are probably positively correlated. Compared with the present experimental paradigm, experience in natural environments would both ease the development of automatic conjunction feature detectors and reduce the cost of lateral feature confusion. The present evidence of automatic conjunction detectors in this experimental paradigm suggest conjunction detectors would be quite effective in natural environments.

In all experiments the CM conjunction was not much different from the CM shape. The slope of the conjunction condition seemed to be dependent on the slope of the shape condition. A small quantitative difference was the only thing that made CM conjunction and CM shape searches different. In the visual detection experiment, a qualitative difference between VM shape and VM conjunction conditions was found. The size of the display had differential effects on detection depending on whether the condition was a VM shape or VM conjunction.

Did two features become unitized? Yes, if unitization means that conjunction search or detection is not qualitatively different from shape search or detection. Only small quantitative differences existed. Unitization did not occur if the conjunction condition had to have the same characteristics of the color condition. The color condition, except in the detection experiment, always seemed different from the other two conditions. It is unreasonable to expect that the conjunction condition, which requires both a color and shape discrimination, should be any better than the more difficult of the two components.

The present results do not support the notion that conjunction search is qualitatively different from feature search. We do not feel the focal attention is necessary to "glue" features together (Treisman and Gelade, 1980). Rather we feel that the stimulus elements (either features or conjunctions of features) have a region of interaction conceptually similar to a defocused lens. The use of focal attention or control processing resources reduces the region of interaction, sharpens focus (Eriksen and Hoffman, 1972), speeds comparisons, enhances texture segregation, etc. We conclude that automatic processing can develop for conjunctions of features. Inconsistencies at the feature level can inhibit the development of automatic processing, and may necessitate special sequencing of conditions to enable automatic processing.

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Footnotes

¹ The term feature will be used loosely here and throughout the rest of the paper. It is not quite clear what distinguishes one feature from another. Garner (1974b, p. 25), when trying to define a feature, could not escape the ambiguity of the term stating that ". . . [feature] has been used to mean either a level on a dimension, a target (as the conjunction of several levels), or as the dimension itself." In using the term loosely, we will call the letter "X", for example, a single feature along a shape dimension.

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